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METROLOGY FOR FUTURE ARMY TEST, MEASUREMENT, AND DIAGNOSTIC EQU--ETC(U)

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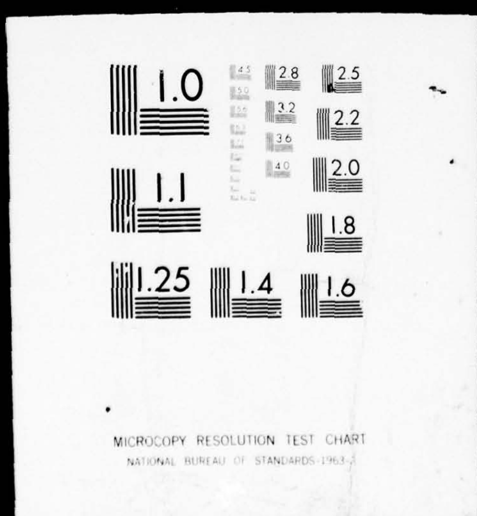

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ECOM-76-1387-F

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METROLOGY FOR FUTURE ARMY TEST, MEASUREMENT, AND DIAGNOSTIC EQUIPMENT (TMDE) REQUIREMENTS

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During the past decade, both the capabilities and technology of Army communications-electronics (C-E) equipment have rapidly advanced. The objective of this study was to forecast the impact of future technology and design trends on the TMDE equipment for the 1985-2000 time frame. The TMDE would be required to support fielded Army C-E equipment. It is anticipated that this forecasted impact cqn influence current and future Army equipment development programs so that any equipment needed to maintain the prime (cont)

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20. ABSTRACT (continued)

equipment items would be available when the prime equipment is fielded. This program will provide specific recommendations concerning measurement requirements and test techniques necessary to support future Army C-E systems and subsystems.

TABLE OF CONTENTS

1 INTRODUCTION

This report represents the final product of the Booz, Allen study, "Metrology for Future Army Test, Measurement, and Diagnostic Equipment (TMDE) Requirements," conducted for the U.S. Army Electronics Command.

1.1 OBJECTIVE

During the past decade, both the capabilities and technology of Army communications-electronics (C-E) equipment have rapidly advanced. Historically, the equipment development process inadequately addressed the maintenance of new sophisticated equipment once it was fielded. This resulted in inadequately equipped depots and other maintenance echelons and, consequently, poor equipment availability and high maintenance costs.

This study was initiated to alleviate these problems. The objective of the study was to forecast the impact of future technology and design trends on TMDE for the 1985-2000 time frame. TMDE would be required to support fielded Army C-E equipment. It is planned that this forecasted impact will influence current and future Army TDME development programs so that the equipment needed to maintain the prime equipment items will be available when the prime equipment is fielded.

1.2 APPROACH

To meet this objective, an advanced study was formulated consisting of the following four tasks:

- Equipment definition
- Technology projection
- Equipment projection
- Test requirements definition.

The approach used for each task is discussed in the following subsections.

1.2.1 Task 1 - Equipment Definition

The purpose of this task was to define the equipment types that would be considered in greater detail during the remainder of the study. An initial list of representative equipment within each equipment category was chosen for further study based on the professional judgment of a panel of senior Booz, Allen engineers. The representative equipment was then discussed with engineers at ECOM to ensure that the list was not overly restrictive.

1.2.2 Task 2 - Technology Projection

The approach used to derive the technology projection for this task was divided into four steps. The first step in the actual forecasting effort was to determine the technology areas which would impact future Army metrology requirements. Through a series of meetings with senior staff, technology areas were selected to cover all aspects of C-E equipment. These areas were discussed with Government personnel and initial agreement was reached on the areas to be considered. Through this process, 19 technology areas were listed. The areas of microelectronic packaging, batteries, fuel cells, and thermoelectic generators were removed from the list since improved performance in these areas will not require improved testing or measurement capabilities. Additionally, automatic test support systems and tactical multiplex systems were removed because they were not basic technology areas.

The second step was to identify both the technical approaches pertinent to each area and the performance parameters which would depict the performance growth of the technology area. This was accomplished through a literature search and interviews with knowledgeable Government experts, which resulted in consistent, meaningful data.

The third step was to collect performance data, some of which was already available from the approach and parameter identification process. During this step, upper and/or lower theoretical performance limits were identified. If no limits were found, the projections were allowed to continue at the predicted rate.

The fourth step was to perform a regression analysis using the breakpoints of the technical approach curves as data points to determine the equation of the trend curve. This equation was plotted and the technical approaches were superimposed upon it. Since performance improvement is exponential, a logarithmic scale was used and the trend curves were plotted on semi-log paper.

The regression analysis was based on the assumption, with some historical validation, that technological progress follows a predictive evolutionary pattern. The postulated pattern, called a trend curve, depicts the underlying trend of increases in performance for each technology area. It is further assumed that the trend will end in only one of two ways:

- A natural physical barrier (such as the speed of light) will be encountered

- Another technology area will totally take over.

Superimposed on the trend curves are the technical approaches (e.g., biploar logic circuits in the technology area of large-scale integrated circuits). These technical approaches form a family of curves that fall into the following categories:

- Historical approaches now obsolete

- Current and overtaking approaches that are well known and of immediate interest

- Future approaches, now unknown, whose emergence is guaranteed by the assumed pattern.

The technical approach curves are similar in shape and consist of three readily identifiable regions:

- Research and development edge. This leading edge of the curve is characterized by a steep slope resulting from rapid increases in performance as the technical approach is brought to maturity.

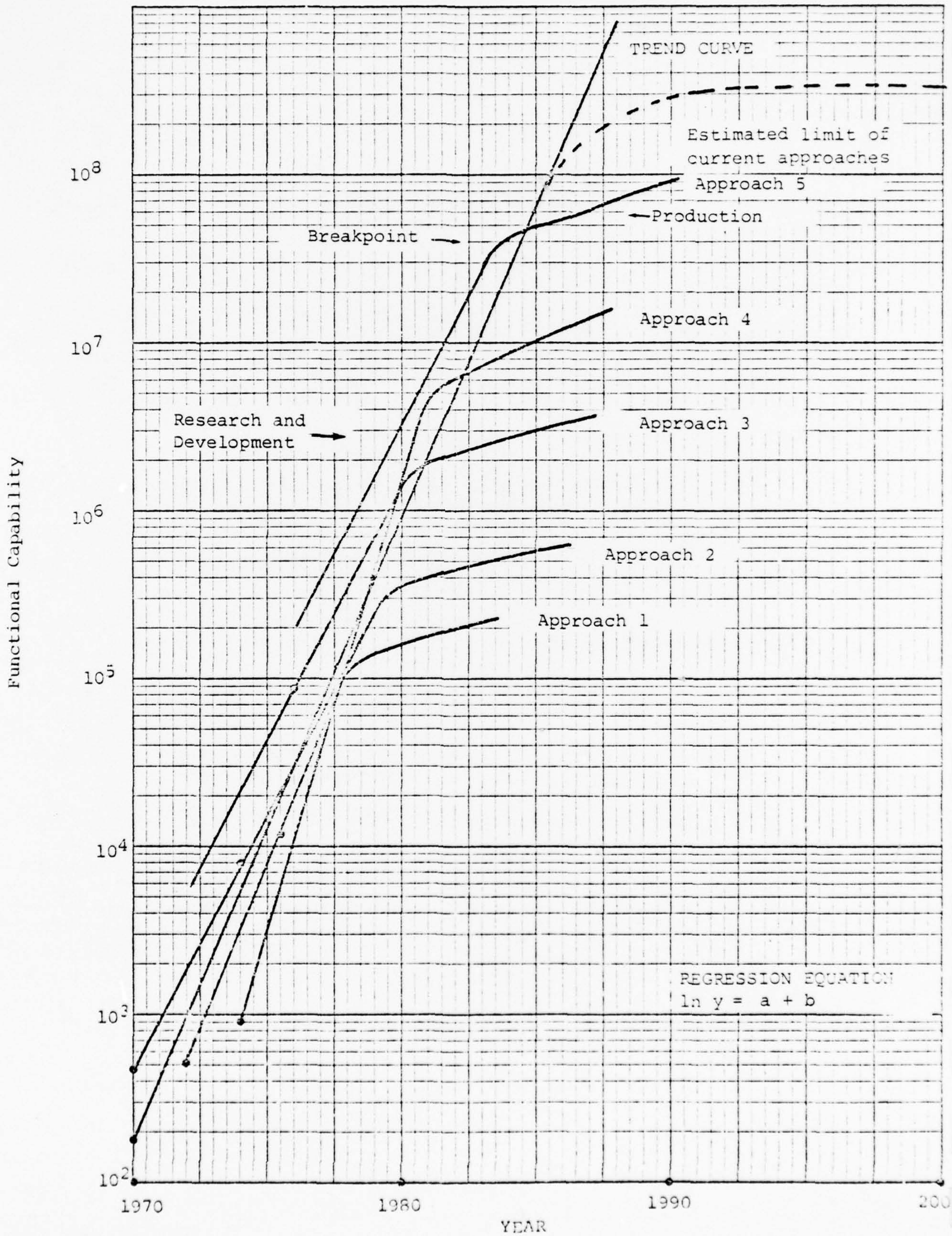
- Production region. The region in which performance increases are less dramatic and occur over longer periods; results in a much flatter slope.

- Breakpoint. The point at which the research and development edge meets the production portion of the curve. The use of breakpoints as historical data points for forming trend curves ensures the use of consistent, easily identified data points in making comparative judgments between technical approaches.

An example of these technical approach curves is shown in Figure 1-1.

FIGURE 1-1

Example of Trend Curve for Technology Forecasting



Trend curves have a tendency to predict what seems to be an unrealistic future. Present technological approaches may have a theoretical limit which is surpassed by the trend curve. New approaches, however, may obey different physical laws and would be constrained to different limits (e.g., in the 1940s, the low power consumption of today's solid-state circuits would have seemed unrealistic in that era of vacuum tubes). For this reason, unless actual physical barriers were found to prevent it, the trend curves were projected to the year 2000 without limiting performance levels.

Not all technology areas could be meaningfully portrayed by trend curves. In some areas (such as avionics displays in which the technologies differ widely and performance parameters tend to be subjective), a more narrative approach was employed. In other areas (such as solid-state RF devices), the available technologies are so immature that trend projection is impossible. Again, a narrative approach was used and performance parameters of present devices were graphically depicted.

1.2.3 Task 3 - Equipment Projection

The approach used for the equipment projection task was to study in detail the equipments chosen during the equipment definition task. Each equipment type was depicted using block diagrams to describe major functions. Each of the blocks in the diagram was studied to determine the type of technology currently used to implement the function. This process established the baseline for the projections.

Each equipment type was studied to determine how the functional blocks would most likely be reconfigured for future systems. The functional reconfiguration was based on equipment projections contained in available literature and interviews held with various ECOM project management personnel. After determining how the new equipment would be functionally organized, each block of the functional diagram was examined by Booz, Allen personnel to determine the type of technology most likely to be used in implementing the function. The functions and technologies were then considered together to identify those functions and/or technologies which would present new or unique problems to test equipment.

1.2.4 Task 4 - Test Requirements Definition

Using the results of Tasks 2 and 3, the equipment expected to be fielded by 1985 and used until 2000, together with the equipment expected to enter the field during the 1985-2000 time frame, was studied by Booz, Allen personnel familiar with Government testing procedures and requirements. Based on this experience, the range of testing requirements for each type of equipment and technology was developed. These requirements are summarized in Section 5. The results of defining the testing requirements for the various equipment and technologies were correlated to identify common requirements.

While the testing requirements were being determined, a second effort was proceeding in parallel. The purpose of this second effort was to determine the advances in test equipment capabilities likely to occur between now and 2000. This study was based upon the results of Tasks 2 and 3 as well as a more detailed search of available literature on test equipment capabilities and applications.

The testing requirements and projected test equipment capabilities were then compared to identify areas in which projected capabilties fell short of projected requirements. The results of this comparison are summarized in Section 6. When projected capabilities fell short of requirements, additional study was undertaken to determine whether the capability shortfall was the result of deficient available technology or improper application of the technology. This study provided recommendations of how to best use Government resources in future programs to ensure that testing requirements would be met.

1.3 SUMMARY OF RESULTS AND CONCLUSIONS

Table 1-1 summarizes the study results. The study has concluded that:

- The C-E equipment that will be in the field or fielded during most of the 1985-2000 time frame is generally either in validation or full-scale development at this time. Most of this equipment is based on shortcomings and requirements identified during the Vietnam and Yom Kippur Wars.

TABLE 1-1
Summary of Study Results

Technical Parameter	Range of Stimulus Capability Required	Range of Measurement Capability Required	Capability Likely in 1985-2000	Comments
Voltage	0 - 100 V	0 - 100 V	Yes	Already exists
Current	0 - 1000 A	0 - 1000 A	Yes	Already exists
Resistance/ Impedance	N/A	0 - 100 MΩ	Yes	Already exists
Frequency	0 - 100 GHz potentially 0 - 1000 GHz	0 - 100 GHz potentially 0 - 1000 GHz	Yes	Current development programs will enable test instrumentation to meet or exceed requirements.
Optical/IR	1 - 0.1 μm	1 - 0.1 μm	Possible	Requires Government support to develop ATE-compatible capability.
Seismic	0.1 - 1000 Hz <0.1 - 100 g	0.1 - 1000 Hz <0.1 - 100 g	Possible	Requires Government support to develop ATE-compatible capability.
Digital Logic	0 - 1 GHz Dynamic	0 - 1 GHz	Yes	Current development programs will enable test instrumentation to meet requirement.
Frequency Hopping	20 - 10,000 hops/sec	20 - 10,000 hops/sec	Possible	If equipment development programs provide capability, technology is available for test equipment program. Government support required.
Spread Spectrum	30 - 50 dB processing gain	30 - 50 dB processing gain	Possible	If equipment development programs provide capability, technology is available for test equipment program. Government support required.

- Most of the equipment currently under development will have an economic life of 15-20 years. Therefore, only one major change in capabilities per equipment type is considered likely during 1985-2000. For those equipments having a major capability upgrading between now and 1985, further major capability changes during 1985-2000 are unlikely.

- The technology used in the equipment in the field during 1985-2000 will generally be that considered state-of-the-art in 1970-80.

- ATE will be required to maintain future C-E equipment. Manual procedures will be incapable of testing equipment performance and maintaining the repair volume expected with the likely available resources.

- Future ATE will generally be capable of meeting projected requirements without additional Government support.

- Additional Government support to develop needed ATE capabilities will be required for testing in the following areas:

  - Fast frequency-hopping/spread-spectrum modem

  - Optical/IR transmitter and detector

  - Seismic sensor.

- The development of the required capabilities is technologically feasible and involves one or more of the following actions:

  - Adapting existing test equipment to be ATE compatible

  - Adapting laboratory-type instruments to a non-laboratory environment

  - Adapting technology developed for other applications to test instrumentation.

- The development of the required testing capability will be dependent upon good software packages to support the ATE hardware. Ongoing Government programs in ATE system software development are adequately supported; however, ATE applications software development will remain expensive and continue to be a relatively high risk area.

These conclusions, together with the recommended actions outlined in Subsection 1.4, satisfy the study objectives. However, the study identified several potential problem areas that were beyond its scope. These problems, together with some preliminary conclusions, are discussed in Section 8.

1.4 RECOMMENDED ACTIONS

Based on the results of this study, the following actions are recommended:

- Existing ATE development programs should be expanded to include development of testing capabilities in the following areas:
  - Fast frequency-hopping/spread-spectrum signal processing
  - Optical/IR circuits
  - Seismic sensor testing and calibration.
- A computerized data base for technology forecasting should not be established. The lack of firm forecasts more than 5 years into the future makes such a data base infeasible. However, periodic efforts should be initiated to update and validate the equations described in Appendix A.

Additional study of the areas discussed in Section 8 appears to be required; however, the development of specific recommendations for these areas was beyond the scope of this study.

1.5 REPORT ORGANIZATION

The remainder of this report is organized as follows:

- Section 2 - describes the scope of this study and the individual equipments studied in detail.
- Section 3 - summarizes the results of the technology projection effort.

- Section 4 - describes the general and specific technical characteristics of C-E equipment to be fielded during 1985-2000.

- Section 5 - describes the test equipment requirements which must be met to maintain fielded C-E equipment during 1985-2000.

- Section 6 - describes the areas in which test equipment capabilities will meet or exceed requirements and those in which capabilities will fall short.

- Section 7 - describes issues requiring further study.

Appendix A details the results of the technology projection. Appendix B describes the regression techniques used during the technology projection; Appendix C presents the technology projection interview results, and Appendix D describes the equipment projections for the 1985-2000 time frame.

2 SCOPE

The generic types of C-E euipment considered during this study were:

- Tactical communications
- Strategic communications
- Avionics
- Target detection and acquisition
- Electronic warefare.

Within each equipment type, representative kinds of equipment were considered in greater detail. The size of the study, together with the range of equipment being considered, dictated that representative equipments within each equipment category be studied in depth and the test equipment requirements of these equipments serve as the requirements for the entire category. The representative equipment types were chosen based on professional judgment using the following considerations:

- Commonality of functions and circuitry with other equipment in the category
- Likely advancement in capabilities
- Relationship of equipment in one category to equipment in other categories
- Known development programs in each category which should represent the next advancement in fielded capabilities.

Based upon these considerations, the generic categories and equipment in each that were studied in depth are listed in Table 2-1.

TABLE 2-1
Generic Categories and Equipment

Tactical Communications	Strategic Communications	Avionics	Target Detection and Acquisition	Electronic Warfare
AN/TTC-39 circuit and message switches	Most of the new equipment entering the DCS during the 1980s will consist of TRI-TAC-developed equipment (possibly modified). Some of the current DCS equipment will be modified to work with the TRI-TAC-developed equipment; however, this equipment will be modified and then maintained by the equipment contractor. Therefore, strategic communications equipment will not offer any additional maintenance problems when compared to tactical communications systems.	Distance-measuring equipment	FIREFINDER	Radar warning receivers/ jammers
AN/TSQ-111 communications nodal control element		Microwave landing systems	Remotely Monitored Battlefied Sensor System (REMBASS)	Optical warning/ jamming devices
AN/TYQ-16 communications system control element		Target/surveillance radars	TACFIRE	
TRI-TAC digital group multiplexer		Collision avoidance systems	AN/TSQ-73	
TRI-TAC LOS and tropo equipment		Flight indicators and displays		
TRI-TAC COMSEC equipment				

3 TECHNOLOGY PROJECTION

This section describes the results obtained from the technology projection performed to establish a technology baseline for both the fielded C-E equipment requiring support during the 1985-2000 time frame and the test equipment available to provide that support.

3.1 TECHNOLOGY AREAS INVESTIGATED

The technology areas investigated are listed in Table 3-1 together with the parameter(s) used to evaluate technical capability in each area. Based upon the results of the initial literature search and confirming information obtained through interviews, the following areas included in the table were eliminated from further consideration:

- Tactical multiplex systems. It was determined that tactical multiplex systems would not offer any unique challenge to equipment support. The technological advances that would be used in tactical multiplex equipment are described under other categories; therefore, there was no justification for retaining tactical multiplex equipment as a stand-alone category.

- Microelectronic packaging. The technological changes that would occur in microelectronic packaging would not affect the capability of test equipment to fault detect/isolate defective parts or circuits. Advances in packaging probably would affect maintenance techniques and practices; however, these effects are beyond the scope of this study.

- Batteries. While it is evident that there will be significant technological advances in battery capabilities over the next 25 years, these advances would have no impact on the ability of test equipment to fault detect/isolate defective units or parts. Therefore, these advances were not relevant to this study.

TABLE 3-1
Technology Areas Considered

Technology Area	Evaluation Parameter
Automatic Test Support Systems	FC*
Army Avionics Display Systems	FC
Image Intensifiers	Recognition Range
LSI	Chip Complexity Circuit Density Function Cost Power Consumption
Digital Voice Coding	FC
Solid-State RF Generators	FC
Optical Communications	FC
Millimeter Wave Systems	FC
Tactical Multiplex Systems	FC
Main Frame Memories	Memory Cost Speed-Access Time Power Consumption Storage Density
Auxiliary Memories	Access Time Mass Memory Cost Capacity Storage Density Data Rates
ADP Displays	FC
Surface Acoustic Wave Devices	FC
Switching	FC
Frequency Control Devices	FC
Microelectronic Packaging	FC
Batteries	Energy Density Storage Life Temperature Specific Cost
Fuel Cells	FC
Thermoelectric Generators	FC

*FC = Functional Capability

- Fuel cells. Similar to batteries relative to use and projected technological advances; fuel cell advances were considered irrelevant to the problems being studied.

- Thermoelectric generators. Similar to batteries and fuel cells relative to use and projected technological advances. No new or unique testing problems will be encountered as a result of advances in thermoelectronic generators and, therefore, they were not considered relevant to this study.

3.2 INTERPRETATION OF RESULTS

The detailed results to the technology forecast are presented in Appendix A. Because of the scarcity of reliable technological projections 25 years into the future, the approach chosen was to extrapolate past performance and near-term projections into the future using regression techniques. These techniques are detailed in Appendix B.

When these techniques are applied to the data points in some technology areas, the projected performance levels seem absurd. Unless a firm physical constraint such as the speed of light was being violated, the projected performance was assumed to be achievable. Different technological approaches often obey different physical laws and are subject to unique constraints. Since the approaches behind a particular technological area in the year 2000 are currently unknown, projections that appear unrealistic today could eventually be quite logical. Historical evidence supports this assumption.

3.3 TECHNOLOGY BASE OF FIELDED C-E EQUIPMENT IN THE 1985-2000 TIME FRAME

The technology employed in fielded C-E equipment tends to be between 10 and 20 years behind the state-of-the-art in a given area. The two basic reasons for this technological are that the:

- Military procurement process generally requires 10 years for equipment to move from the validation phase through development and production into fielded use

- Economic life of C-E equipment is generally 20 years.

Since the military procurement cycle typically takes 10 years to complete, the technology proven feasible during the validation phase is between 8 and 10 years behind the state-of-the-art when the equipment is finally fielded. This technology lag is relatively constant even then the procurement process is expedited. In order to quickly field equipment meeting urgent requirements, older, more familiar technology is used to minimize development problems.

Limited funds and the necessity to fully realize the economic payback lifetime for the equipment (i.e., to fully amortize high cost or large volume inventory items), dictate that once equipment is fielded, it will not be quickly replaced. Only when a new development renders existing equipment so obsolete that it cannot accomplish its primary mission is equipment replaced before the end of its full economic life.

Therefore, C-E equipment fielded during the 1985 time frame generally will employ 1975 technology. Similarly, equipment fielded during the 2000 time frame will use 1985-90 technology. The technology projections for fielded C-E equipment in the 1985 time frame are very reliable since the technology to be used is already several years old. The technology projections for the 2000 time frame are still reasonably reliable since they are less than 10 years into the future.

3.4 RESULTS OF TECHNOLOGY PROJECTION

The results of the technology projection performed are detailed in Appendix A; they are briefly summarized in the following subsections.

3.4.1 Functional Capability Versus Requirements

The performance levels achieved by the various technologies of interest will, by 2000, far exceed the demands presented by currently known requirements. Therefore, future emphasis will be on cost reduction rather than maintaining the current rate of technology growth, particularly when the two are incompatible. For example, in the case of a transmission system, rather than indefinitely increasing the traffic-handling capacity (which might be technologically possible), development programs will be directed at cost reductions and improving such physical parameters as size, weight, ruggedness, and capability for surviving a hostile environment. In many areas, cost/performance tradeoffs will serve to balance expenditures and actual performance.

Just as the growth of functional capability will be limited by cost considerations, greater utilization will be made of the available capability. For example, in the case of transmission systems, all traffic classes (voice, data, video, etc.) will be carried in a secure, digitized format over a single medium; unused time slots will be detected and filled with queued information from various different sources. Thus, although capability may be restricted by cost considerations, the available capability, in terms of occupancy and variety of functions performed, will be maximized. This trend will generally be true of all technology areas considered.

3.4.2 Analog Versus Digital Signal Processing

It is impossible to definitively state when analog signal processing will no longer be used in new equipment designs. However, by 2000, most new equipment will use digital signal processing in its basic design. This is the result of increased capabilities of digital circuitry, the size reductions being achieved through LSI, and the advantages of digital versus analog signal processing, such as:

- Lossless transmission
- Error-correction capability resulting in virtually distortionless reproduction of the original signal
- Ease of implementing security capabilities.

The trend to increasing digital circuitry will also reduce the applicability of manual test procedures to fault detection and isolation.

3.4.3 Ultimate Limitation to Size Reduction

Although advances in LSI technology could theoretically increase component density and greatly reduce component size, the necessity for human operators to access the controls associated with the equipment limits this trend. Though the thickness dimension of future equipment may approach zero, sufficient front panel area must be retained to permit the operator to manipulate control knobs and switches, and read and interpret indicators.

4 EQUIPMENT PROJECTION

This section describes the types of equipment that are likely to be fielded during the 1985-2000 time frame. General trends in equipment development are discussed first, followed by discussions by equipment category for the 1985-2000 time frame. The specific detailed descriptions, including equipment configuration diagrams, are discussed in Appendix D.

4.1 GENERAL TRENDS

Although there will be obvious differences in the way equipment within the various categories advances in capability, a number of underlying trends exist in the way capability advancement will be achieved. These are described in the following subsections.

4.1.1 Use of Microprocessors

Future equipment, subsystems and systems will, in general, be controlled by microprocessors integrated into the basic design of the equipment subassemblies. The complexity of these microprocessors will vary widely and will be dependent on the specific application. At one extreme are the microprocessors which will replace discrete Boolean logic circuits or arrays through a software implementation of the required functions. Microprocessors implemented at this level will be relatively hidden in that the user will probably not realize that the equipment item contains any embedded computer resources. Also, through trying the capabilities of the several microprocessors likely to be contained in a single large equipment into a distributed capability, the capability of any one microprocessor will be increased many times.

At the other end of the microprocessor implementation spectrum are those microprocessors with capabilities which overlap those of minicomputers or even larger computers. For example, the AN/TTC-42 unit level switchboard being developed by the Marine Corps as part of the TRI-TAC Program will probably be controlled by a computer system using redundant microprocessors. The AN/TTC-42 will be a fully automatic 150-line circuit switch. To the user, this microprocessor will seem to be a full-capability computer system, and the user will be fully aware that he is interacting with a computer system.

Increased use of microprocessors will enable new equipment to adapt itself to changes in its operational environment; this will significantly reduce the equipment's susceptibility and vulnerability, and will result in more survivable and reliable equipment. The failure of single components in an equipment may not significantly affect equipment performance since the microprocessor will provide a "work-around" capability.

4.1.2 Man/Machine Interface

The man/machine interface will become oriented towards the machine adapting to human requirements rather than the man adapting to the limitations of a machine. The equipment displays will present information to the equipment operator using simple narrative and symbolic data. For complex information presentation, pictorial displays (such as map displays with "overlays") will be used.

In addition to these standard display formats, the user will be able to request additional information on specific portions of the display. This display enhancement will be available through the information storage/retrieval capabilities of the embedded computer resources previously discussed.

Inputting information to these future systems will also become greatly simplified. Since many of the systems will largely be automated, information will be input via preformatted magnetic tape cassettes. If it is necessary to enter additional information during normal equipment operation, this information will be input via VDU keyboard or optical character readers. Punched cards or tape will virtually disappear as a data entry technique.

4.1.3 Replacement of Analog Circuits by Digital Circuits

The current trend of replacing analog techniques and circuitry by digital techniques and circuitry will continue and accelerate until virtually all signal processing is accomplished via digital techniques. Equipment fielded during the 1985-2000 time frame will be all digital unless some function cannot be accomplished with current digital technology. In those few instances where analog techniques will continue to be used, the analog circuitry will be interfaced and controlled by the digital circuitry in the remainder of the equipment. In this manner, the entire equipment/system will be placed under digital control.

Coupled with this switch from analog to digital circuitry, the use of LSI circuitry will increase. This increasing use of LSI circuitry will not result in throwaway modules or circuit boards, however. As the electronics are better able to accommodate a given set of requirements using fewer, cheaper components, the requirements will increase. The resulting electronics will still fit in the same physical space occupied by current circuitry; however, extensive use of miltilayer circuit boards and custom LSI chips will make each board so expensive that the boards must be repaired rather than discarded and replaced. For example, the current net radio will be replaced by the SINCGARS family of radios. SINCGARS will incorporate COMSEC and antijam capabilities into a single package that is likely to be smaller and lighter than current net radios.

4.2 NEW FIELDED EQUIPMENT: 1985 TO 2000

The new equipment to be fielded and the relatively new equipment that will already be in the field during the 1985-2000 time frame are discussed in the following subsections in the context of the equipment categories considered during the study.

4.2.1 Communications

4.2.1.1 TRI-TAC Equipment

The equipment being developed under the TRI-TAC Program will become the standard for providing both strategic and tactical switched communications. This equipment will begin to be fielded by 1985. During the 1985-2000 time frame, the TRI-TAC equipment will replace the current inventory equipment until these equipments compose virtually the entire switched communications inventory by the year 2000.

The technology being employed in TRI-TAC equipment is generally CMOS, NMOS, and PMOS LSI technology. The biggest exception to this is the projected use of fiber optics cable to interconnect major system elements in physical proximity. This use of fiber optics cable is projected to be in the field by 1990. The first application of fiber optics cable in TRI-TAC will be the replacement of coaxial cable used in high-speed data transmission between the AN/TTC-39 and AN/TSQ-111.

4.2.1.2 Net Radio

The SINCGARS family of net radios is to be fielded during the 1985 time frame. This family of radios will replace all net radios currently in use including: aircraft VHF radios; armor- and jeep-mounted radios; and manpack radios. It is anticipated that by 2000, the SINCGARS family will have replaced almost all current inventory radios in these areas.

The SINCGARS family of radios will use frequency hopping to provide anti-jam protection. COMSEC capability will be provided by a plug-in module. The technology that is likely to be employed in SINCGARS is CMOS, PMOS, or NMOS LSI.

4.2.2 Avionics

The general trends in avionics equipment will be to change the system/equipment configuration and make more general use of fiber optics cable to interconnect the equipment. Avionics equipment is in the process of changing from discrete equipments (each having dedicated sensors and displays) to an integrated system using shared sensors into a central processor that uses a single integrated display to convey information to the pilot.

Coupled with the trend to an integrated avionics system and the resultant increase in the use of digital signal processing will be the increasing use of fiber optics cable in place of wire. Signal multiplexing will permit a significant weight reduction associated with internal signal processing and transmission. Since weight is a limiting factor in aircraft performance, the additional cost of fiber optics will be justifiable and fiber optics will be widely used.

The individual subsystems or elements of the avionics system are detailed in Appendix D. All of these elements will use technology that is typically used in current equipment such as CMOS, PMOS, or I^2L LSI, with the exception of the fiber optics cable and associated optical drivers and receivers.

4.2.3 Target Detection and Acquisition

The following equipment from four major programs is currently entering the field or will enter the field during the 1980-90 time frame:

- FIREFINDER
- Remotely Monitored Battlefield Sensor System (REMBASS)
- TACFIRE
- AN/TSQ-73.

These equipments are discussed in greater detail in the following subsections.

4.2.3.1 FIREFINDER

The FIREFINDER Program is developing equipment which will detect and locate the source of unfriendly artillery and mortar fire. Two approaches are currently under consideration for meeting the established requirements: (1) the use of phased-array radar to scan for incoming rounds and then calculate origination point based on flight profile; and (2) the use of seismic detectors to detect strength and direction of seismic vibrations coupled with radar to locate the source of unfriendly fire. Both approaches have proven feasible; however, the combined radar/seismic approach offers size and weight advantages. This approach may make man-portable systems feasible for use against unfriendly mortar fire.

The technology employed in these systems is basically that used in other equipment developed during the 1970-75 time frame. The one exception to this generalization is the use of seismic detectors in the man-portable mortar location equipment. The technology used in these detectors is the current state-of-the-art; however, the application is unique.

4.2.3.2 REMBASS

The equipment being developed by the REMBASS Project Office is designed to provide surveillance information on enemy troop and vehicle movements through multiple sensors using a variety of technical approaches, including radar, seismic/acoustic, optical/IR, and chemical sensors. The outputs of these sensors are tied to a central data collection point, correlated, and analyzed to provide a real-time intelligence capability.

The technology to be used in these sensors and the balance of the system is expected to be more advanced than that used in previously discussed systems/equipment. This is because much of the equipment is still in advanced development or less advanced in engineering development. It is likely, therefore, that LSI technology used in this equipment will tend to be CMOS and I^2L as a result of the requirement for real-time processing and low power consumption. The technology used in the various sensors is expected to be similiar to that used in the data collection and correlation equipment.

4.2.3.3 TACFIRE

The TACFIRE System is currently being fielded; this equipment is expected to be in the field throughout the 1985-2000 time frame. TACFIRE is designed to correlate information concerning potential targets for artillery fire and direct the resulting artillary fire to obtain the most effective use of the available resources.

As stated, TACFIRE is currently being fielded. The technology used in this system is typical of that used in equipment developed during the 1970 time frame. The computer system is the same as that used later in the AN/TTC-39.

4.2.3.4 AN/TSQ-73

The AN/TSQ-73 is the HAWK "missile minder" system. Its concept is similiar to TACFIRE except that the resources being managed are HAWK missile batteries rather than artillery batteries. The AN/TSQ-73 is currently undergoing testing prior to its deployment.

The technology used in the AN/TSQ-73 is similiar to that used in the TACFIRE, AN/TTC-39, and other systems developed during the 1970-75 time frame.

4.2.4 Electronic Warfare

Electronic warfare systems being developed basically fall into two areas: (1) warning and homing receivers; and (2) jammers. The scope of electronic warfare has recently broadened in response to new technology applications. With the wider application of optical/IR target designation and related guidance systems, the warning, homing, and jamming capabilities that have developed to defeat radar illumination and radar-directed gun or missile fire need to be developed to defeat optical/IR illumination. The development of new warning and homing devices and an associated jamming capability is currently in process; new equipment is planned for fielding during the 1985-2000 time frame.

The electronic warfare equipment to be fielded during the 1985-2000 time frame will use LSI technology such as CMOS or I^2L in its processing circuitry. The final amplifiers of the radar jammers are likely to continue using tube technology to provide required output power. The final amplifiers of the optical/IR jammers will be some type of controllable light source such as narrowbeam Xenon arc lamps for the noise jammers and tunable lasers for the deception/spoofing jammers.

5 CAPABILITY REQUIREMENTS FOR TEST EQUIPMENT

This section discusses the stimulus and measurement capabilities that will be required of any test equipment used to maintain fielded Army C-E equipment during the 1985-2000 time frame. These capabilities will generally be required regardless of the maintenance support level at which the equipment is employed. Closely related to the capabilities required of support test equipment are the built-in test equipment (BITE) capabilities designed into the prime equipment during the development process. Since the BITE capabilities effectively set a upper bound to complexity of the unit under test (UUT) which must be tested by the support test equipment, prime equipment BITE is discussed first followed by the type of test data required for each equipment category of interest. This section concludes with a discussion of the specific stimulus and measurement capabilities required of future test equipment.

5.1 PRIME EQUIPMENT BITE CAPABILITY

BITE allows an equipment operator/repairman to isolate certain faults without the aid of external test equipment. The level (e.g., assemblage, PC card, component) to which any fault may be isolated depends on the sophistication of the BITE, which can vary from a manually-switched analog meter (used by an operator to check equipment operation at various internal stages through a set of predefined procedures) to an automatic fault detection system which automatically displays fault occurrences and identifies the faulty module to the operator. The amount and sophistication of the BITE used in a particular equipment depends on considerations which include:

- Maintenance philosophy
- Equipment complexity
- Equipment cost
- Equipment quantity
- Available external test equipment.

If an equipment operator's maintenance responsibilities are limited to changing fuses and sending entire assemblages of failed equipment to upper maintenance echelons, it is only necessary to indicate when an item has failed. On the other hand, if the operator is responsible for replacing failed modules or subassembly elements, the BITE should indicate which module or subassembly has failed. In this manner, the equipment availability is maximized through minimizing the equipment's mean time to repair (MTTR).

To simplify fault isolation, it is usually desirable to have more sophisticated BITE in complex equipment. However, as the equipment becomes increasingly complex, the hardware and software needed for automatic fault isolation using BITE also becomes increasingly complex. Therefore, it may be necessary for the BITE implementation and fault-location capability used in very complex equipment to be at relatively higher (less detailed) levels than is true for simpler equipment. If this tradeoff is not considered, a significant portion of the overall design effort will be devoted to providing the specified level of BITE.

As part of the BITE implementation level/equipment complexity tradeoff, equipment cost must be considered. As the BITE implementation design effort increases, the proportion of the development and production costs associated with BITE also increases. Under ordinary circumstances, it is not easy to justify BITE which costs a significant amount (greater than 10 percent) of the total equipment cost. Thus, inexpensive, simple equipment is not expected to contain a significant amount of BITE, while more costly and more complex equipment can be expected to contain significant amounts of BITE. As previously stated, the effort and cost required to implement BITE to a fixed level may rise proportionately faster than the overall equipment cost as the basic equipment becomes more complex. Therefore, for more complex equipment, a fixed percentage of BITE cost to equipment cost may result in proportionately less capability for complex equipment.

Fault isolation for equipment which will be fielded in large quantities can probably best be performed using external test equipment located at a central test facility. Unique, complex equipment which is fielded in very small quantities probably should have any necessary special test equipment built in. For equipment falling between these two extremes, the specified BITE implementation level should be the subject of a tradeoff study. This approach is cost-effective and assures that special testing needs will be met in the field.

The final consideration in determining the level of BITE to be specified for an equipment item is the availability of existing test equipment capable of supporting the prime equipment. If widely used (especially automatic) test equipment is available, it is probable that tradeoffs would indicate a low-level implementation of BITE coupled with providing adequate automatic test equipment-compatible test points. If this approach is specified, the cost of providing the required test support is reduced to developing and maintaining the required automatic test equipment (ATE) test software. This cost is generally lower than the cost of providing both the hardware and software internally to the equipment.

In summary, BITE must be tailored to fit the needs and uses of each specific equipment item. Large, complex items fielded in small quantities would generally benefit by the inclusion of a large amount of BITE, possibly including automatic fault isolation capability. The use of large amounts of BITE in widely fielded equipment is not as well justified. The best approach for these types of equipment appears to be limited BITE, indicating the general operational status of the equipment and the status of the lowest replaceable unit coupled with more specific fault isolation performed by ATE at centralized support locations.

5.2 PARAMETRIC DATA REQUIREMENTS

Before equipment faults can be diagnosed, the status of certain equipment parameters must be known. The equipment configurations in Section 4 and Appendix D will be impacted by technological advances in the areas of:

- Digital logic
- Optical/IR devices
- RF generation and receiving.

Parametric data requirements for each area are discussed in the following subsections.

5.2.1 Digital Logic

Rapid advances in the state-of-the-art of digital logic technology are expected to result in denser LSI chips, smaller module packaging, more complex circuits, and denser circuit boards. These advances will also result in a limited number of available circuit test points in post-1985 digital logic circuits.

The parameters available for fault detection and isolation of logic circuits in the post-1985 era will include:

- Circuit board input/output (I/O) voltages and currents
- Circuit board test patterns
- Power
- Switching frequency
- Chip I/O voltages and currents
- Chip I/O test patterns
- Specific accessible test points.

Manual fault-isolation procedures using these parameters would be lengthy and tedious. The tester would also need to be highly trained; consequently, manual testing would be very costly. Therefore, troubleshooting logic circuits in the post-1985 era will require some type of automatic test system for supplying the necessary stimuli and recording and comparing the actual output responses to a predetermined output pattern.

The requirement for some type of automated test system stems from the denser chips, denser circuit boards, and fewer test points. Each area is very dependent upon the other. Circuit board density will increase almost ten-fold as a result of the denser LSI chips which will permit more complex circuitry to occupy less chip and circuit board area. As a result of the area reduction and increased circuit complexity, the test points formerly available in a large circuit consisting of either discrete components or more chips of lower density will no longer be available for use in manual testing procedures. An automatic test system provides not only a more accurate method for testing but also a faster and more efficient method for testing large, complex logic circuits. As the system becomes sufficiently complex, automatic testing is the only feasible testing method.

5.2.2 Optical/IR Devices

Advances in laser technology, low-loss optical fibers, semiconductor optical sources and detectors, and electro-optic signal devices will result in an increase in applications of optical/IR techniques in C-E equipment in the post-1985 time frame. Devices designed to interface optical/IR devices with communications or target detection and acquisition equipment will have the following parameters available for use in both manual and automatic fault detection and isolation:

- Bit rate
- Wavelength
- Output power
- Input excitation
- Rise time
- Noise equivalent power.

5.2.3 RF Generation and Receiving

Solid-state RF devices are expected to replace tube devices such as the klystron and traveling wave tube (TWT) for most lower power RF generator and transmitter applications by 1985. Tube technology will continue to be used for high-power applications such as EW jammers. These solid-state devices are expected to operate at higher frequency ranges, higher efficiency, lower noise, and higher output power. With this trend continuing to the post-1985 time period, the following parameters are expected to be available for both manual and automatic fault detection and isolation:

- Frequency
- Output power
- Gain
- Noise/figure
- Intermodulation distortion.

5.2.4 Seismic Devices

Seismic devices are expected to find wide application in area protection and target detection and acquisition systems. The devices will be capable of detecting the seismic vibrations which result from personnel or vehicular movements. The dynamic range of these devices will enable the data correlation equipment associated with the sensors to distinguish personnel movement from vehicular movement. These devices will have a direction-sensing capability so that combining the output of two or more of these sensors will enable the data collection/correlation equipment to pinpoint the location of the source of the vibrations using triangulation techniques.

The parametric data available for these devices will consist of:

- Status messages returned in response to status request messages
- Bit rate
- Parity patterns of output messages
- Output messages generated in response to seismic input.

The only realistic capability for testing these modules and devices will be by using ATE. The actual seismic detector will probably be an analog device; however, an analog-to-digital converter and probably a simple microprocessor will be coupled with the device. The entire module will probably be packaged (potted) into a single unit so that the only access to the module will be via the control/reporting lines or the seismic input surface.

5.3 TEST EQUIPMENT CAPABILITIES REQUIRED

This subsection discusses projected test equipment capabilities required to maintain deployed post-1985 C-E equipment. Requirements identified in this subsection apply to both stimulus and measurement capabilities since all the C-E equipment/systems studied include some type of transmitter and receiver.

Stimulus/measurement capabilities required to maintain post-1985 C-E equipment fall into four general categories:

- RF signal
- Optical/IR
- Digital signal
- Seismic.

The following subsections discuss, in general terms, identified requirements for testing capabilities for each category. Table 5-1 relates specific requirements to each equipment type described in Section 4, except for seismic detectors.

5.3.1 RF Stimulus/Measurement Requirements

The need will exist to both generate and monitor RF signals at frequencies up to 100 GHz. Transmitter output power over the 1- to 10-GHz band must be measured for power levels from less than 1 watt to over 1 Megawatt. Power measurements from 10 to 100 GHz will be required for power levels up to 20 kilowatts. Most RF generators and receivers will use digital transmission. Data rates will vary from 20 pulses per second to 20 Mb/s.

5.3.2 Optical/IR Stimulus/Measurement Requirements

Optical signals must also be generated and monitored to test post-1985 C-E equipment. Optical transmitters used in fiber optics transmission systems will be low level (<5 mW). The data rates used in fiber optics transmission systems will vary from 100 b/s to potential rates of 1000 Mb/s. A more reasonable upper limit to bit rates for military communications systems will be 100 Mb/s.

5.3.3 Digital Signal Stimulus/Measurement Requirements

Testing of digital equipment will require the capability to generate and monitor digital signals having faster pulse rates and narrower pulse widths than presently used. Data rates in excess of 20 Mb/s will be used; digital circuit operating rates may extend to 1 GHz. In addition, a number of C-E equipment configurations will use signals with pulse widths on the order of 1 microsecond or less. To test specific items of digital logic equipment it will be necessary to dynamically generate specific bit patterns and monitor the circuit output bit pattern. To isolate faults, several different patterns may be necessary, depending on circuit complexity. This specific requirement must be examined for each equipment item.

TABLE 5-1
Test Capabilities
Requirements Matrix

Equipment	Operating Frequency	Pulse Width (μsec)	Pulse Rate (Pulses/sec)	Data Rate	Output Power
Distance-Measuring Equipment	1025-1150 MHz	3.5	20-150	N/A	50-2000 W
Radar Beacon System	1-5 GHz	0.9	50-3500	1.8 Mb/s	2 kW
Primary Surveillance Radar	1-3 GHz	0.6-2	300-10,000	N/A	5 mW
Microwave Landing System	5-35 GHz	0.2-0.7	40-2000	N/A	50 kW
Collision Avoidance Systems	1.6-5 GHz	25-40	50-1000	N/A	100-200 W
Tactical Tropo	1-5 GHz	N/A	N/A	0.1-5 Mb/s	1-10 kW
LOS Transmission	5-60 GHz	N/A	N/A	0.1-20 Mb/s	10-1000 W
Radio Satellite	5-35 GHz	N/A	N/A	5-60 Mb/s	10-50 W
Laser Satellite	0.1μm (λ)	N/A	N/A	100 Mb/s	100 mW
Net Radio	30-88 MHz	N/A	N/A	16 kb/s	10-100 W
Fiber Optics Transmission	1μm (λ)	N/A	N/A	1-1000 Mb/s	5 mW
Digital Logic	Up to 1 GHz	N/A	N/A	Up to 1 GHz	N/A
Electronic Warfare Systems	2-1000 GHz	0.1-5	5-5000	N/A	1-100 W

The requirement to test digital circuit boards having embedded microprocessors will necessitate that ATE have the capability to distinguish between hardware and software failures. Microprocessor hardware failures cannot be repaired; software failures can be repaired. If the software failure is a basic programming error, all fielded systems will require a software update to correct the failure.

5.3.4 Seismic Stimulus/Measurement Requirements

Generally, seismic stimulus/measurement requirements will tend towards calibrated stimulus generation. No need to generate seismic disturbances has been identified. It will be necessary to precisely measure seismic stimuli, however, so that the response of the UUT can be accurately determined.

Seismic detectors deployed during the 1985-2000 time frame will be capable of measuring seismic disturbances having the following characteristics:

- Frequency: 0.1 to 1000 Hz
- Acceleration: <0.1 to 100 g
- Directional location: less than 20 degrees arc
- Magnitude of dislocation: ± 0.001 to ± 1 cm.

The capability to generate known seismic disturbances with this range of characteristics will be required of test equipment maintaining post-1985 sensor systems.

6 TEST EQUIPMENT CAPABILITIES VERSUS REQUIREMENTS

This section describes the projected test equipment capability requirements for maintaining C-E equipment during the 1985-2000 time frame and compares these requirements to the test equipment capabilities that are likely to exist in the absence of any new Government-supported research and development programs. The areas in which projected capabilities will meet or exceed requirements are discussed first, areas in which projected capabilities will fall short of equipments.

6.1 TEST EQUIPMENT CAPABILITIES EXPECTED IN 1985-2000

This subsection describes the technical areas and supporting rationale for determining if projected test equipment capabilities during 1985-2000 will meet or exceed the capabilities required to maintain C-E equipment fielded during this time frame. Overall systems are discussed first followed by detailed discussions of individual technical areas.

6.1.1 Automatic Test Systems

The Army is already funding an ATE development program called Electronic Quality Automatic Test Equipment (EQUATE). Under this program, several ATE assemblages (AN/USM-410) have been built by RCA and are being used to support several Army C-E equipment development programs. The AN/USM-410 is designed for fault isolation, performance, and calibration testing on both analog and digital printed circuit boards, module subassemblies, and assemblies. The AN/USM-410 is designed to test units varying from simple power supplies to highly complex C-E equipment.

The design and layout of the AN/USM-410 allow the measurement/stimulus capability to be upgraded as improved test equipment becomes available. Thus, with a few exceptions, the AN/USM-410 can be expected to satisfy the basic measurement/stimulus requirements of C-E equipment fielded between 1985 and 2000. The major exceptions are in the areas of microprocessor/software verification, optical/IR testing, and seismic sensor testing.

Experience with current ATE support systems for Army C-E equipment has shown that an excessive amount of modules returned to the depot for repair are in good condition. Before the condition of a module can be determined, the depot-level ATE must functionally check the module. To reduce the unnecessary load on depot-level ATE and to provide ATE capability at intermediate (direct support) levels, the Contact and Repair Test Equipment (CARTE) program has been initiated. The objective of this program is to provide an easily transportable ATE unit that has a processor controlled mainframe providing dedicated maintenance functions to a type of equipment such as net radios, tank or vehicle automatic equipment, tactical switched communications, etc. The capability to support a given type of equipment will be provided through interchangeable plug-in stimulus/measurement modules and reloadable software packages stored on magnetic tape or plug-in ROM circuit boards. This program will use available technology and provide an intermediate capability between equipment BITE and the full capability ATE such as found in the AN/USM-410. Since the CARTE program is essentially adapting current capabilities to fit a particular need, the stimulus/measurement instrument limitations that apply to depot-level ATE also apply to CARTE.

The TRI-TAC Program is currently considering a nodal support concept for maintenance of the major TRI-TAC equipment elements. Under this concept, a maintenance shelter having ATE capable of supporting the AN/TTC-39, AN/TSQ-111, AN/TYQ-16, and TRI-TAC line-of-sight and tropo radios, etc., will be deployed where a sufficient concentration of equipment justifies its deployment. This concept is not necessarily in conflict with CARTE since the required ATE could be the CARTE equipped with the appropriate stimulus/measurement modules and software package and mounted in the shelter. The nodal support concept has not yet progressed beyond concept formulation.

6.1.2 Electrical Parameter Testing

Electrical parameter testing includes the generation and measurement of the following electrical signal characteristics:

- Voltage
- Current
- Frequency or pulse counting.

Through the measurement of these parameters, it is possible to calculate values for resistance, impedance, and time.

The capabilities of existing manual and ATE-compatible test instruments already exceed the requirements that will likely be encountered in new equipment fielded during the 1985-2000 time frame. The capability available in manual test equipment is generally available in ATE-compatible test instrumentation. No new or extended requirements were identified during this study.

6.1.3 Logic Testing

Logic testing involves generating a sequence of logic patterns to the UUT, monitoring the output patterns obtained, and comparing the UTT-generated logic patterns to the patterns which should have been generated in response to the sequence of input patterns. Logic testing is generally conducted in two different manners: static and dynamic.

In static testing, a single logic pattern is input to the circuit under test, the circuit responds, and the output is determined and compared to the correct output. If the output is incorrect, the output pattern is analyzed to determine the possible fault locations. Then, a new logic pattern is input or manual probing or a combination of techniques is used to isolate the fault location. Throughout this procedure, the logic circuitry is being operated at a rate far below that at which the circuitry normally operates, hence the name static testing.

One criticism of static testing is that it does not truly test the operational capabilities of the circuitry. Many of the faults that develop in logic circuitry are only evident or only occur when the circuitry is operating at its design speeds. Dynamic logic testing attempts to test logic circuitry under real operating conditions. Sequences of input logic patterns are generated and outputs analyzed at the speeds at which the circuitry is designed to operate. In complex logic systems, the input patterns used to stimulate the circuitry under test are often dependent upon the output patterns generated in response to previous input patterns. Thus, the tester must be capable of responding realistically to the circuitry under test while still recording, comparing, and generating logic patterns which will enable him to fault detect and isolate the circuitry.

Technologically, the test equipment available in the 1985-2000 time frame will be capable of generating, recording, and comparing the required logic patterns to perform both static and dynamic logic testing. The problem associated with dynamic testing is to develop the test software package needed to test the logic circuits. If done manually, this is very difficult, and requires substantial amounts of time from highly skilled test programmers. It is, therefore, very expensive to generate and validate these software packages.

Some advances in automatic test program generation (ATPG) have been made recently. Generally, these programs generate the associated test program by a modified trial-and-error method. A known good circuit is connected to the tester and the tester generates patterns and records the associated outputs. Two problems are associated with this ATPG approach, the difficulties of: (1) determining that the first circuit board is really functioning correctly; and (2) being able to introduce a truly comprehensive set of faults into the circuitry so that the tester can detect and isolate the faults which will occur in real circuits. While real and significant, these problems do not negate the basic conclusion - the available ATE will be capable of testing the logic circuits that will be used in C-E equipment fielded during the 1985-2000 time frame.

6.1.4 Waveform Generation

To test the various types of circuits used in C-E equipment, it is necessary to generate simple and complex waveforms which include the following types:

- Sine
- Square
- Triangle
- Ramp
- Pulse
- Gate.

To provide the required waveforms, these waveforms can be combined through various modulation techniques such as AM, FM, sweep, triggered, or gated. The capability to generate these waveforms exists today in ATE-compatible test instruments. If the need to generate new waveforms is developed to test new C-E equipment, developing suitable ATE-compatible waveform generators should be straight-forward, since the same circuitry and techniques used in the prime equipment would probably be usable in the test instruments.

6.1.5 RF Generation

The RF generation capability discussed in this subsection is the generation of the basic RF signal. The generation of RF coupled with fast frequency hopping or spread-spectrum techniques is expected to present problems for future test systems. The impacts of these techniques on ATE are discussed in Subsection 6.2.1.

The requirement to generate RF signals up to 100 GHz will exist during the 1985-2000 time frame. Current ATE-compatible RF generators are capable of reaching 40 GHz. Since the technology used in future prime equipment will be available for use in future ATE-compatible RF generators, no problem is foreseen in developing the required RF generation capability when needed.

The requirement to generate RF signals in the 100- to 1000-GHz range may exist during the 1985-2000 time frame, however, the need for such a capability is unclear. Based on available information, research efforts are being conducted in this region of the spectrum; nevertheless, potential applications for this technology are unknown. Only minor problems are expected in developing any RF generators within this frequency range if the requirement arises. As with the capability below 100 GHz, any technology used in the prime equipment will probably be available for use in the required test equipment.

6.2 PROJECTED DEFICIENCIES IN TEST EQUIPMENT CAPABILITIES

This subsection describes those areas in which the projected capabilities of test equipment during 1985-2000 are expected to fall short of requirements in the absence of any new Government-supported efforts. This does not imply that providing the required capabilities is technologically impossible. However, current Government and industry programs will not result in equipment having the required capabilities since, generally, no current programs exist to provide the required capability. To provide the required test stimulus/measurement capability, additional Government-supported development programs will be needed in the following areas:

- Fast frequency hopping/spread spectrum
- Optical/IR
- Seismic.

These areas are discussed in greater detail in the following subsections.

6.2.1 Fast Frequency Hopping/Spread-Spectrum Stimulus/Measurement Capability

With the introduction of SINCGARS as well as various new EW systems into the inventory, the maintenance of equipment that uses frequency-hopping or spread-spectrum techniques to defeat jamming will be a reality. Overt jamming has not been encountered in commercial applications and, therefore, industry has no incentive to spend funds developing ATE-compatible test instruments capable of testing systems that use fast frequency-hopping or spread-spectrum techniques. No Government programs have been identified which will lead to development of the needed ATE-compatible test instruments.

To adequately test systems using frequency-hopping or spread-spectrum techniques will require processor-controlled test systems capable of testing embedded microprocessors. Since these test instruments must be processor controlled, the development effort probably should be added to other ongoing ATE development programs.

6.2.2 Optical/IR Stimulus/Measurement Capability

By 1990, equipment in the field will begin to extensively use optical and fiber optics technology. The primary use of these technologies will be to replace bulky or heavy copper wiring. Thus, much of the internal data transfers of avionics systems and the inter-shelter data transmission at tactical communications nodes will be accomplished over fiber optics cable.

Currently, no ATE-compatible optical/IR test instruments exist. Some test instruments capable of being used in the field do exist, but they have been designed to maintain specific systems and do not have the capability to interface ATE. Providing the required ATE capability to maintain C-E equipment using optical transmission/detection or fiber optics cable will require ATE-compatible stimulators and measurement equipment.

Again, since an ATE-compatible capability is desired, a development effort in conjunction with an ongoing ATE development effort should be funded. The exact capability to be provided by this generator/measurement instrument will need to be established based on the prime equipment capabilities.

6.2.3 Seismic Stimulus/Measurement Capability

During the 1985-2000 time frame, several new systems that use seismic detectors will be entering the field. Unlike the disposable/nonrecovered seismic detectors that have generally been deployed to date, these detectors will be reused and deployed in much more sophisticated systems. Therefore, the capability to measure the performance and maintain these sensors will have to be established.

Systems using seismic sensors will have to be maintained using ATE because of the systems' complexity. Therefore, the stimulus/measurement capability for seismic sensors should be ATE-compatible. Again, the most effective development strategy would be to fund an additional effort as part of an ongoing ATE program.

One unique aspect of the seismic stimulus/measurement development effort is that the testing capability requirement can be satisfied by developing a calibrated stimulator. There are no known development efforts to develop a seismic generator for use against unfriendly forces; therefore, to test the fielded equipment, it is unnecessary to develop a calibrated seismic measurement capability. However, such a capability may be desirable to calibrate the ATE-compatible seismic stimulator to be developed.

7 FUTURE CONSIDERATIONS

This section describes observations and some initial conclusions resulting from this study. These subjects and study areas were beyond the scope of this study; however, they should be studied since their resolution will affect the development of future test equipment and the maintenance procedures for future C-E equipment.

7.1 REQUIRED USE OF ATE

The use of ATE in maintaining future C-E equipment will center on the degree and level of its use. Maintenance of future C-E equipment will require ATE because of:

- Equipment complexity
- Cost of manual maintenance procedures
- Volume of equipment to be repaired.

Current and future C-E equipment and systems are increasing in complexity, making manual fault detection and isolation impractical. With LSI technology allowing over 10,000 devices to be placed on a single chip, it is becoming impossible for an individual to detect all but the grossest level of faults. Fault isolation is even more difficult to implement manually. Circuit densities and complexities today are such that functions formerly requiring bays of equipment for implementation are now accomplished on a single circuit board. Also, many of the techniques used in today's equipment are only feasible because of embedded computer resources. A computer interface is required to implement any testing of these functions since human responses are not quick enough.

The time, training, and personnel costs of using manual test procedures are related to the equipment complexity problem. Extensive training is required to accomplish any manual test procedures on a complex circuit board. Once a person has completed this training, his pay levels must reflect a high skill level. With manual test procedures, the MTTR for even moderately complex circuit boards averages several hours compared to several minutes when automatic procedures are used. This extra time, coupled with the pay level for highly skilled technicians, makes manual testing exceedingly expensive.

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The third factor that dictates the use of automatic testing of future C-E equipment is the volume of equipment to be repaired. This volume will increase. To perform the required volume of repair, many more highly skilled technicians and the test equipment to support these technicians would be required. These technicians are not available today and are unlikely to be available in the future. Therefore, the only feasible solution to this problem is automation of the fault detection and isolation functions.

7.2 MAINTENANCE PHILOSOPHY AND ORGANIZATION

The current maintenance philosophy and organization used to implement that philosophy is as follows:

- Organizational support - basically performed by equipment operator. Requires the operator to identify and replace faulty modules using equipment BITE and ground support equipment (GSE) supplied.

- Intermediate level (direct) support - performed by trained maintenance technicians. Maintenance technicians troubleshoot equipment to determine which submodule is faulty.

- Depot level - the faulty submodules are subjected to detailed fault detection and isolation by highly skilled personnel. When the faulty component is located, it is replaced and the submodule is returned to service.

The exact disposition of the faulty module at any of these levels depends upon the results of logistic support analyses. An equipment assemblage will follow this progression if real maintenance actions can be accomplished at each level.

With the introduction of very sophisticated BITE and the increased testing speeds of ATE, an intermediate maintenance level may no longer be required. It may be possible to increase the initial BITE capability of the equipment coupling that capability with increased depot-level ATE availablity, and to eliminate the entire intermediate maintenance level. Because one maintenance level is eliminated, including the attendant personnel and equipment, the overall maintenance system may be cheaper to support even though the initial equipment cost may be higher and some additional personnel and equipment are required at the depot.

The trend in terms of capability and cost-effective use of resources indicates that a basic change in maintenance system and philosophy is required.

APPENDIX A

TECHNOLOGY PROJECTION

APPENDIX A

TECHNOLOGY PROJECTION

A.1 Introduction

This appendix contains the detailed results of the technology projections which were used to determine the performance capabilities likely to be found in future Army communications-electronics (C-E) equipment. These capabilities will drive future Army test and diagnostic equipment requirements.

A.1.1 Objective

The objective of this appendix is to project advances that can be anticipated in technology areas having a major impact on Army C-E equipment from the present to the year 2000. The projection data is to be used to forecast the impact of future technology on metrology requirements to the year 2000.

A.1.2 Data Presentation

The method used to depict technological progress was to plot trend curves of the performance level associated with any given technology area. These trend curves are generally exponential, as progress seems to follow exponential laws.

Any technological projection is based on the assumption, with some historical validation, that technological progress follows a predictive evolutionary pattern. The postulated pattern, called a trend curve, depicts the underlying trend of performance increases in the technology area. It is further assumed that the trend will end in only one of two ways:

- A natural physical barrier (such as the speed of light) will be encountered.
- Another technology area (such as the replacement of the gas lamp with the electric light bulb) will totally take over.

Superimposed on the trend curves are the technical approaches (e.g., bipolar logic circuits in the technology area of large-scale integrated circuits). These technical approaches form a family of curves that fall into the following categories:

- Historical approaches now obsolete

- Current and overtaking approaches that are well known and of immediate interest

- Future approaches, now unknown, the emergence of which is guaranteed by the assumed pattern.

The technical approach curves are similar in shape and consist of three readily identifiable regions:

- Research and development edge. This leading edge of the curve is characterized by a steep slope caused by rapid increases in performance as the technical approach is brought to maturity.

- Production region. Occurs when the technology is brought to production, and is characterized by less dramatic performance increases occurring over longer periods resulting in a much flatter slope.

- Breakpoint. The point at which the research and development edge meets the production portion of the curve. The use of breakpoints as historical data points for forming trend curves ensures the use of consistent, easily identified data points in making comparative judgments between technical approaches.

These technical approach curves are examplified in Figure A-1. This figure illustrates the three technical approaches of image intensifiers.

Trend curves can be unrealistic. Present technological approaches may have a theoretical limit which is surpassed by the trend curve. New approaches, however, may obey different physical laws and would be constrained to different limits (e.g., in the 1940s, the low power consumption of today's solid-state circuits would have been unforeseen in that era of vacuum tubes). For this reason, unless actual physical barriers were found for doing otherwise, the trend curves were projected to the year 2000 without limiting performance levels.

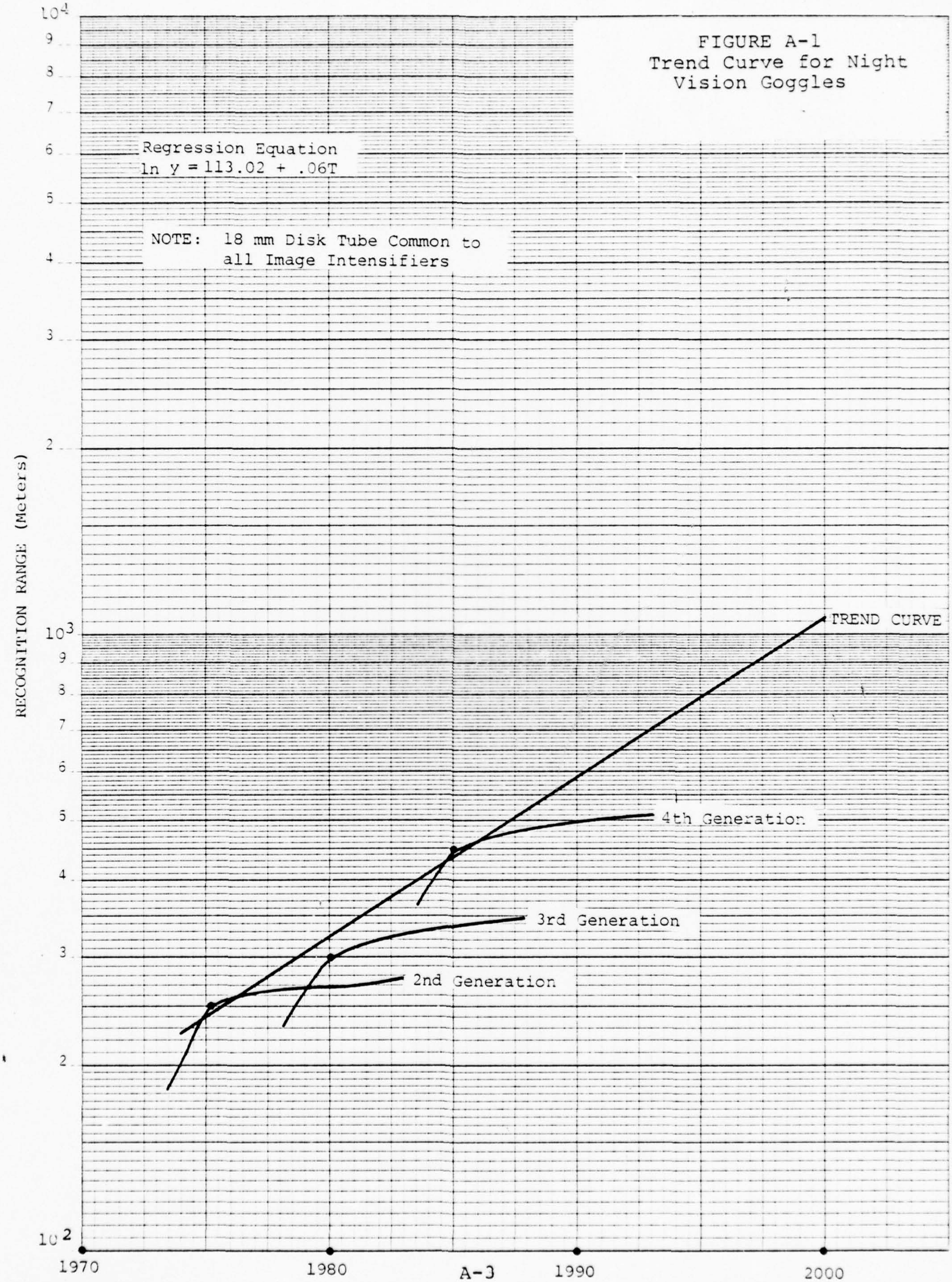


FIGURE A-1
Trend Curve for Night Vision Goggles
Regression Equation
ln y = 113.02 + .06T
NOTE: 18 mm Disk Tube Common to all Image Intensifiers
RECOGNITION RANGE (Meters)
10^4
9
8
7
6
5
4
3
2
10^3
9
8
7
6
5
4
3
2
10^2
1970
1980
1990
2000
TREND CURVE
4th Generation
3rd Generation
2nd Generation

Because of the lead time necessary to translate technologies to fieldable equipments, and the desire to maximize the useful life of any fielded equipment, Army electronic equipment in use through the year 2000 will be using the technologies of 1990 or earlier. Hence, for the purpose of determining metrology requirements, projections to 1990 are the most significant.

Not all technology areas could be meaningfully portrayed by trend curves. In some areas (such as avionics displays, in which the technologies differ widely and performance parameters tend to be subjective), a more narrative approach had to be employed. In other areas (such as solid-state RF devices) the available technologies are at or near theoretical limits and new technologies are so immature that trend projection is not possible. Again, a narrative approach was used and performance parameters of present devices were graphically depicted.

A.1.3 Organization

This appendix is organized into two sections, the introduction and the technology forecasts. The introduction contains the objective and some background material. The forecast section contains the detailed results of the technology forecasts for each area.

A.2 Technology Forecasts

Projections were made for technology areas that are considered critical to the testing and maintenance of future generations of C-E equipment and systems. Table A-1 lists the specific technology areas considered and the performance parameters used to describe capability within each area. Each area, together with the specific results, is detailed in the following subsections.

A.2.1 Army Avionics Display Systems

A.2.1.1 General

The basic function of avionics display systems is to visually provide usefully formatted data to the pilot concerning the aircraft's on-board integrated avionics system.

TABLE A-1
Technology Areas Considered

Subsection	Technology Area	Achievement Level/ Performance Parameter
A.2.1	Army Avionics Display Systems	Functional Capability
A.2.2	Image Intensifiers	Recognition Range
A.2.3	Large-Scale Integration	Chip Complexity Circuit Density Function Cost Power Consumption
A.2.4	Digital Voice Coding	Functional Capability
A.2.5	Solid-State RF Generators	Functional Capability
A.2.6	Optical Communications	Functional Capability
A.2.7	Millimeter Wave Systems	Functional Capability
A.2.8	Main Frame Memories	Memory Cost Speed-Access Time Power Consumption Storage Density
A.2.9	Auxilary Memories	Access Time Mass Memory Cost Capacity Storage Density Data Rates
A.2.10	ADP Displays	Functional Capability
A.2.11	Surface Acoustic Wave Devices	Functional Capability
A.2.12	Switching	Functional Capability
A.2.13	Frequency Control Devices	Functional Capability

Functional and technical capability will increase from single information items displayed on cathode ray tubes (CRT) using discrete component electronics and analog signals, to multiple item presentations on solid-state displays using LSI circuitry and digital signals. Therefore, airborne display systems will become lightweight and rugged, and will use minimum power, with efficiently designed pilot/display system interface. Modular display panel designs will permit universal installations in all Army aircraft systems. Processor control of the display will accommodate a wide spectrum of test signal inputs. The generation display system of 2000 will be able to accommodate the low-level flight mission profile and wide range of ambient light conditions that will characterize the Army aviation environment.

A.2.1.2 Present Generation

The present generation of avionics display systems is represented by the rapidly obsolescing family of airborne display systems comprised of CRTs driven by analog signals with associated discrete component circuitry, warning lights on the cockpit panel, and other single-item presentations. Coding is limited to alphanumeric, preformatted messages or GO/NO GO lamp indications. A limited amount of graphic display coding is available. The disadvantages of conventional CRTs are that they:

- Require a high cathode voltage which is hazardous to the air crew
- Are not easily ruggedized
- Are difficult to package
- Have a relatively short expected life and reliability.

Displays using light-emitting diodes (LED) are becoming common. LEDs improve display visibility and reliability. The ruggedness and low power dissipation of LEDs are well suited to the rugged helicopter cockpit environment. In competition with the LED, the liquid crystal display (LCD) may also be used.

LEDs are semiconductor diodes designed and constructed such that visible light is emitted when sufficient voltage and current are applied to the diode junction. LEDs are in commercial production and three colors are available: red, green, and amber. LEDs are a good choice for alphanumeric displays using a relatively small number of characters. Practical character size is 3/4" high or less. LEDs have numerous advantages over CRTs, some of which are:

- Ruggedness
- High reliability
- Long life
- Availability of three colors
- Low power
- Low cost
- Low voltage - compatible with LSI logic
- High efficiency (100 lumens/watt, compared to 35 lumens/watt for incandescent lights).

Recent advances in LED displays include the use of light pipes to increase image area and viewing angle of the display, and pulsing the display using higher peak power, but at no increase in average power. A pulsed display is perceived by the human eye as a brighter image.

Future LEDs may not show greatly reduced power consumption since they already are very efficient. However, costs can be expected to decrease significantly as production quantities increase. The cost of an 8-digit LED display should be less than $1 by 1980 based on general microelectronic device costs.

LCDs like LEDs, are most suitable for small alphanumeric displays. These devices do not emit light; rather, they scatter ambient light or light provided by a source within the display. The device is fabricated by sandwiching a thin layer of liquid material with crystalline properties between glass plates upon which transparent electrodes have been deposited. When a voltage of sufficient magnitude is applied, the crystalline material between the electrodes becomes misaligned, scattering incident light. This provides sufficient contrast for a display. The advantages of LCDs over LEDs are:

- Low voltage required - LSI compatible
- Low power - less than 1 milliwatt for eight digits
- Small size

- Low cost
- Visible in bright ambient light
- Large size display relatively inexpensive.

A.2.1.3 <u>1980 Generation</u>

The 1980 generation will use flat, high resolution CRTs with digital, solid-state display electronics. The use of color to enhance information content and pilot comprehension will be incorporated in models of this generation. Large alphanumeric and graphic displays will be possible. Night vision goggles will interface with the 1980 generation display system.

The flat-screen CRT provides two basic advantages over conventional CRTs:

- Thin (2" for an 8½"x6" screen)
- Digital switching and random scanning capability.

The flat-screen CRT uses an area cathode that is the same size as the phosphor screen. Electrons are emitted from the entire cathode area and accelerated toward the screen. The images are controlled by four planes of control elements. These elements will either block a beam if a negative voltage is applied or pass it upon application of a positive voltage. Present prototype units have control elements which form 512 characters using a 5x7 dot matrix. As with conventional CRTs, flat-screen versions require high acceleration voltages. Production models are expected to be up to 12" square. Multicolor displays will be possible in later models.

LED displays will be used for instrument readout and small alphanumeric panels. LCDs will not be used unless their operating temperature range is extended below the -20° C which limits current versions. Solid-state displays will not yet be economical enough to replace CRTs for large displays with graphic capabilities.

A.2.1.4 <u>1990 Generation</u>

This will be a transition generation before the advent of processor-controlled, all solid-state displays. The flat-screen CRT will be replaced by higher peformance plasma displays. The plasma display is created by trapping a flourescing gas (e.g., neon) between two plates of glass. Electrodes are deposited on the glass plates with horizontal lines on one plate, vertical lines on the other. The gas flouresces at the electrode intersections when a sufficient voltage is applied between electrodes. Advantages of plasma displays compared to CRTs are:

- Ruggedness
- Probable longer life
- No high voltage
- Digital display control (i.e., easily interfaced with digital circuitry)
- More flexibility for packaging.

Disadvantages of plasma displays include:

- Brightness control more difficult
- Complicated drive circuitry
- Single color only.

The U.S. Air Force plans to use a plasma screen for displaying alphanumeric data in both the Airborne Warning and Control System and the Airborne Command Post. The performance parameters of these displays are:

Size	12-1/2" x 12-1/2"
Dot matrix size	1024 x 1024
Resolution (lines/inch)	83
Voltages required	140 AC 25 DC
Power consumption (watts) (screen & drive electronics)	200.

Solid-state displays will be employed as in the 1980 generation. Problems with cost and washout under high ambient light conditions will keep LED readouts from wide use. If the low temperature operating range of LCDs is extended to military limits, they could be used for large displays in avionics applications. However, this is not expected to occur.

A.2.1.5 2000 Generation

Generation in 2000 will consist of a completely solid-state, all-digital display system. Salient features of this system could be expected to include:

- High visibility over a wide range of ambient light conditions (starlight to sunlight)
- Digital display addressing techniques which will permit a single display subsystem to display a wide variety of inputs
- Lower power consumption
- Solid-state processor with moderate memory capacity, i.e., 16K through 32K characters
- High resolution
- Common instrumentation module that will be universal to all Army aircraft with add-on modules to accommodate special mission requirements
- Large screen display.

A.2.2 Image Intensifiers

Image intensifiers provide amplification of low-level ambient light. Their major applications are night vision goggles, starlight scopes, and crew-served weapons sights. The performance parameter used to represent the growth of the technology is recognition range. This is defined as the distance over which the device operator can obtain a positive indication of the general nature of a target. Because of the importance of the parameter, recognition range measurement capability will be required of future metrology systems.

To provide better performance, future image intensifiers will operate at a longer wavelength, (i.e., from 0.9 to 2 microns), with extended spectral response to maximize usage of the available radiation. This will allow objects at lower temperatures to be more visible in future devices. The actual nature of image intensifier technology beyond 1985 is unknown. It is expected, however, that the current trend of performance improvement will continue. Figure A-1 (previously presented) and Figures A-2 and A-3 describe the projections to the year 2000 of the three major applications, (i.e., goggles, starlight scopes, and crew-served weapons sights, respectively). Table A-2 describes the key parameters which distinguish present and future generations, and indicates the distinctions between goggles, starlight scopes, and crew-served weapons sights. The generations are defined as follows:

- Second (present) - uses evaporated photo cathode and includes inventory items such as:
  - AN/PVS-5, Night Vision Goggles
  - AN/TVS-5, Crew-Served Weapon Sight
  - AN/PVS-4, Small Starlight Scope.
- Third - will use gallium arsenide photo cathode and extend the operating wavelength, i.e., 1.06 μm intensifiers.
- Fourth extends the operating wavelength to the 1-2 μm region. Transferred electron and tunnel emitter cathode will be employed.

A.2.3 Large-Scale Integration

A.2.3.1 General

The term large-scale integration (LSI) refers to semiconductor integrated circuits that have 500 or more components on a single monolithic chip. LSI technology can place as many as 10^6 components on a single chip measuring 300 mils on a side.

LSI chips are batch fabricated on silicon substrates using several steps of masking, etching, ion diffusion, and vacuum deposition of semiconducting, insulating, and conducting materials.

Circuits are fabricated using large masks which are photoreduced to the proper size. The reduction process restricts the achievable component density but is not the most serious limitation. The etching process involves the use of photoresist exposed to ultraviolet light through the mask. The minimum achievable spot size using an

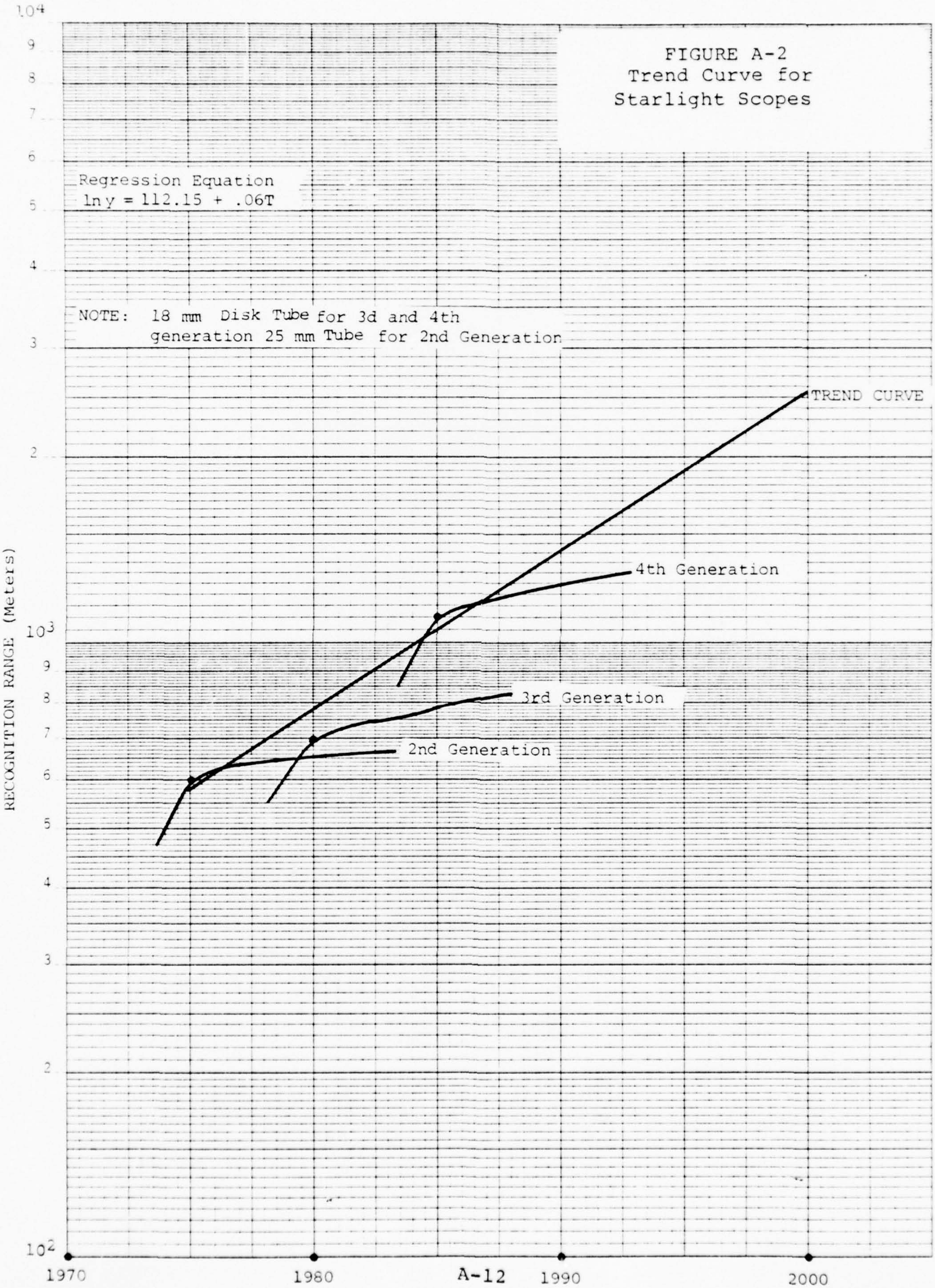


FIGURE A-2
Trend Curve for
Starlight Scopes
Regression Equation
ln y = 112.15 + .06T
NOTE: 18 mm Disk Tube for 3d and 4th
generation 25 mm Tube for 2nd Generation
TREND CURVE
4th Generation
3rd Generation
2nd Generation
RECOGNITION RANGE (Meters)
10^4
10^3
10^2
1970
1980
1990
2000

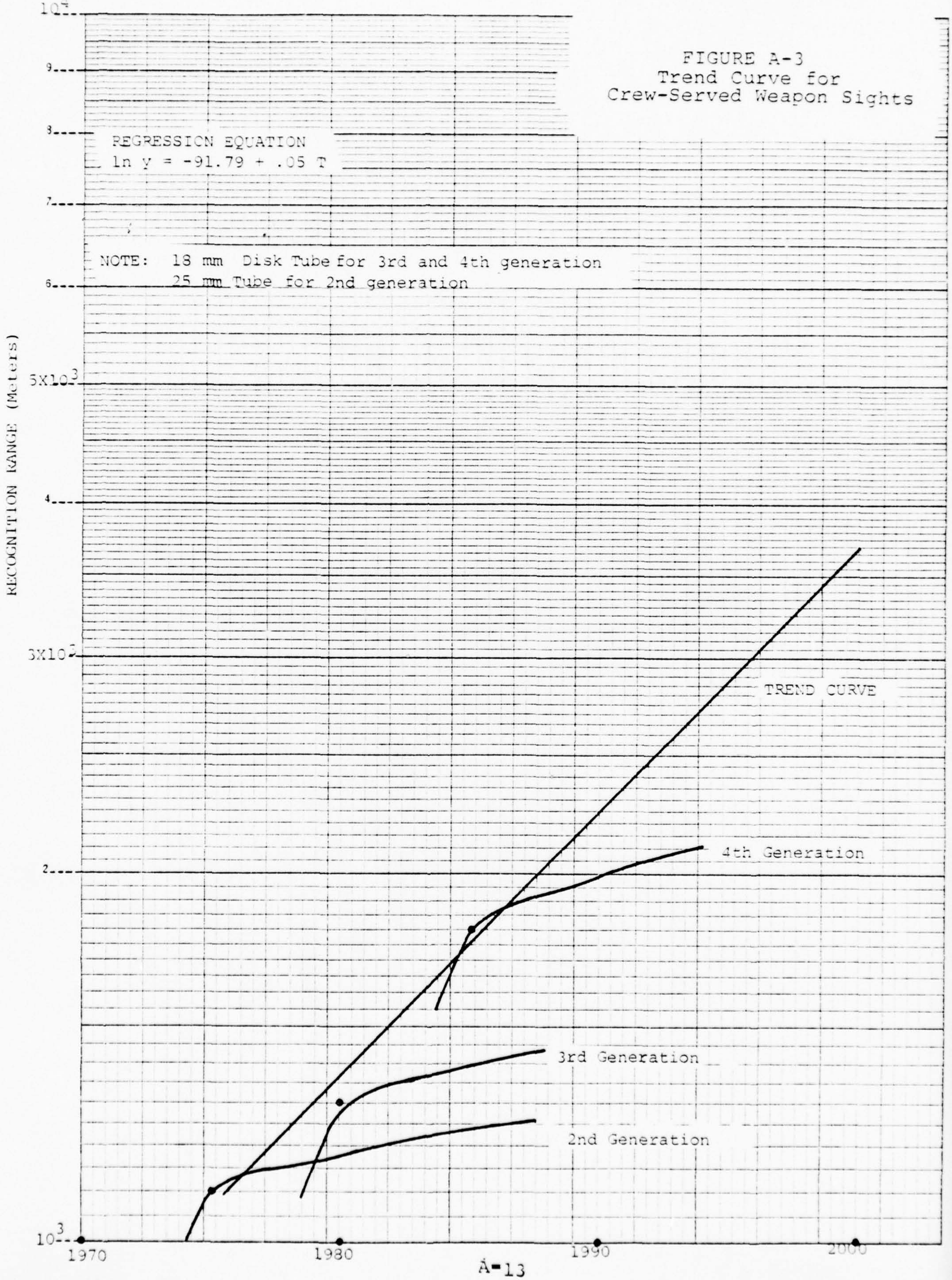


FIGURE A-3
Trend Curve for
Crew-Served Weapon Sights
REGRESSION EQUATION
ln y = -91.79 + .05 T
NOTE: 18 mm Disk Tube for 3rd and 4th generation
25 mm Tube for 2nd generation
RECOGNITION RANGE (Meters)
10^4
9
8
7
6
$5X10^3$
4
$3X10^3$
2
10^3
1970
1980
1990
2000
TREND CURVE
4th Generation
3rd Generation
2nd Generation

TABLE A-2
Key Parameters of Image
Intensifier Devices

System	Field of View (Degrees)		Weight (lbs.)		Recognition Range (Meters)			Cost (Thousands)		Operating Wavelength (Microns)		
Generation	2	3&4	2	3&4	2	3	4	2	3&4	2	3	4
Goggles	40	60	2.0	<1.0	250	300	450	$3.8	$3.4	0.9	1.06	1-2
Small Starlight	15	15	3.75	1.3	600	700	1100	$3.2	$2.4	0.9	1.06	1-2
Crew-served Weapons Sight	9	9	7.50	2.5	1100	1300	1800	$3.1	$2.4	0.9	1.06	1-2

ultraviolet beam is on the order of 5000Å. A further improvement in density is possible using electron beams which can be focused to a spot size of 500Å.

An additional impediment to achieving high densities is the diffusion of ions in unwanted directions. Increased line spacing is required because spreading occurs perpendicular to the line being formed. Ion beam deposition shows promise here, but more research is needed. The development of electron beam photolithographic techniques (circa 1986-90) will permit resolutions of 100Å in LSI arrays.

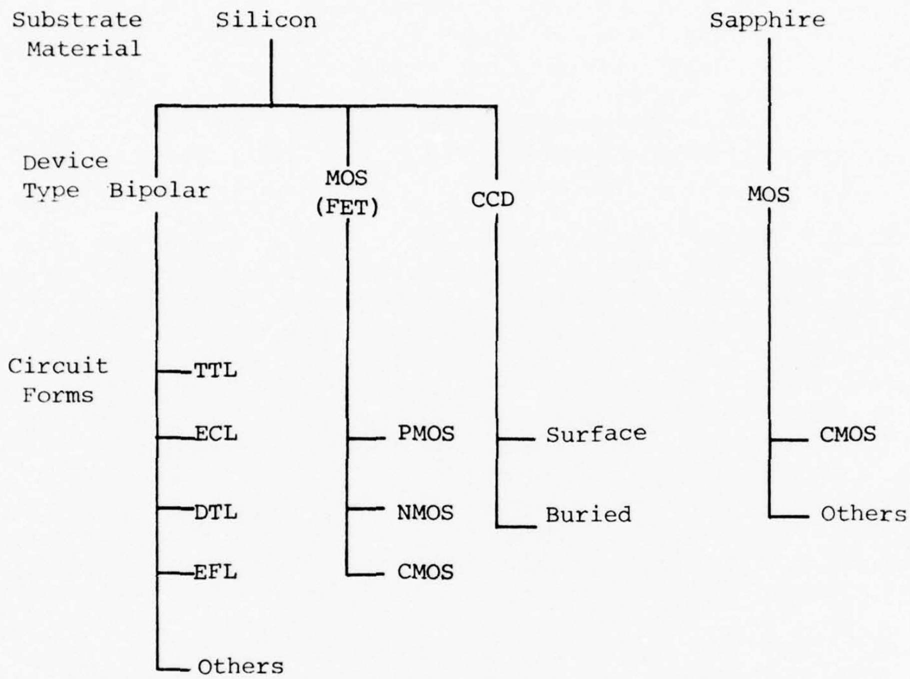
LSI techniques can be employed on many technologies. Figure A-4, adopted from a chart by Dr. B. Dunbridge, is a graphic presentation of these technologies. These are categorized by substrate, device type, and circuit forms. Bipolar devices employ NPN or PNP junction transistors in integrated form. These are basically current-controlled devices. Metal-oxide-semiconductor (MOS) devices depend on field effects and are basically voltage-controlled devices. Charge-coupled devices (CCD) use MOS-type fabrication to form MOS capacitors. They are not active devices and require fewer elements. CCDs can be constructed entirely on the surface of the substrate allowing higher component densities then those achievable with MOS technology.

Other than the choice of LSI technology, the designer has to choose between various circuit forms which offer advantages that must be considered for the intended application. The circuit forms include:

- Transisor-transistor logic (TTL)
- Emitter-coupled logic (ECL)
- Diode-transistor logic (DTL)
- Emitter-follower logic (EFL)
- P-channel MOS (PMOS)
- N-channel MOS (NMOS)
- Complimentary MOS (CMOS).

LSI devices decrease equipment costs. These savings are realized through the fabrication of many circuit functions on a single piece of substrate and fabricating many identical circuits during a single production run.

FIGURE A-4
Types of LSI Technology



Substrate and fabrication costs are relatively constant, hence cost reductions per circuit function are realized by increasing circuit density and manufacturing yield. Significant opportunites for improvement exist in both areas.

The four performance parameters selected to portray the trends in LSI technology are:

- Circuit density (bit/in^2)
- Circuit complexity (gates/chip)
- Function cost (cents/bit)
- Power consumption (mW/bit) for circuits with speeds of 1-10 MHz.

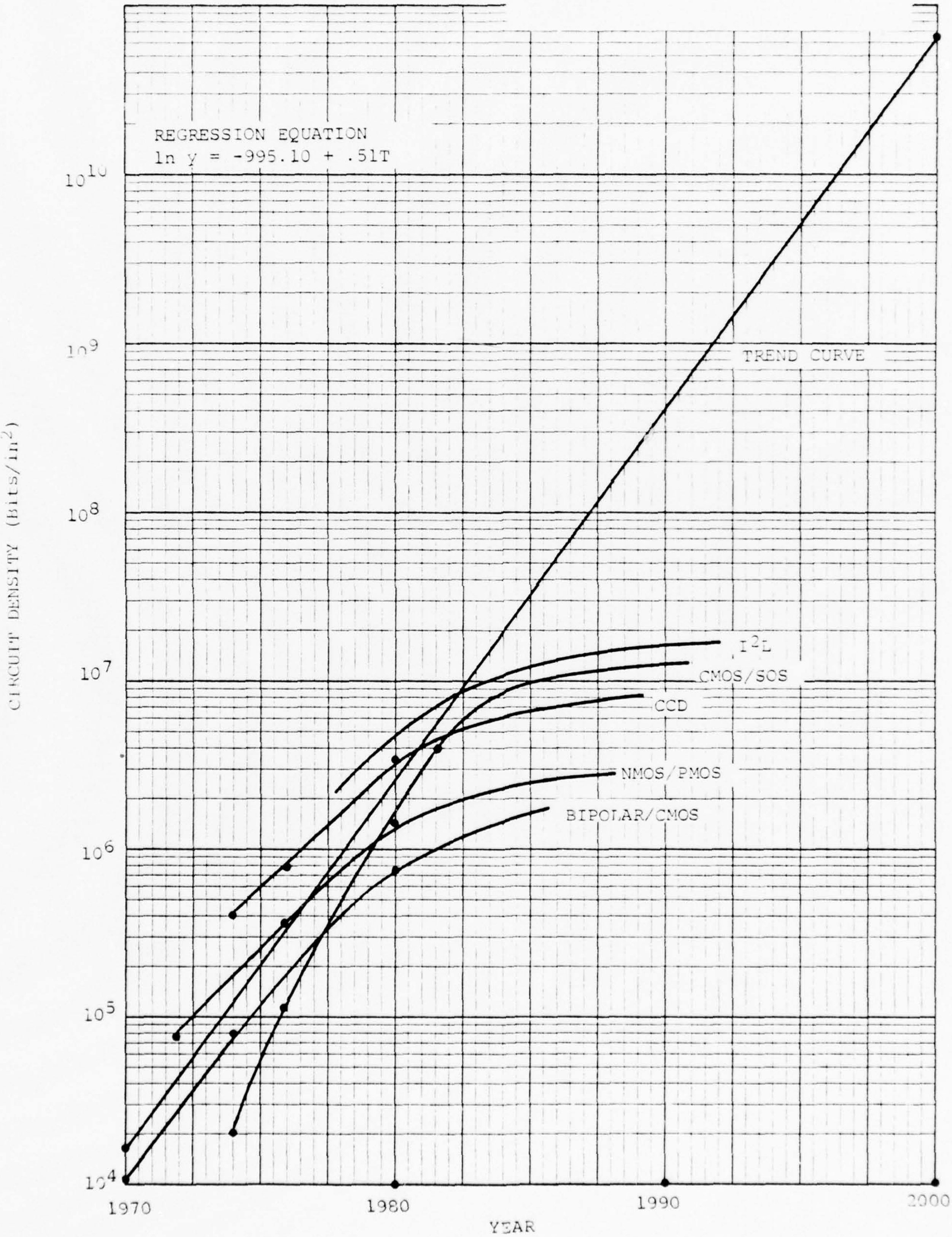
These parameters are the most critical when considering the size, power, and cost reductions that will eventually translate into correspondingly improved Army C-E equipment. Chip complexity, circuit density, and power consumption will have a significant impact on metrology. These parameters are described in the following subsections.

A.2.3.2 Circuit Density (bits/in^2)

Component density and economical chip size determine the number of components per LSI chip. Figure A-5 shows the density trends for various LSI technologies. Bipolar density is less than NMOS/PMOS density because the junction formation requires more area. CMOS requires two active devices per gate and thus is half as dense as either PMOS or NMOS. The use of an insulating sapphire substrate for CMOS/SOS allows greater density than CMOS or bipolar. CCD density is more than twice that of PMOS or NMOS because of the simpler structure involved. Bipolar integrated injection logic (I^2L), a recent addition to the LSI family, is also shown.

The ECOM long-range goal for chip density is 10^7bits/in^2. It is anticipated that C-E equipments fielded up to the year 2000 will employ LSI circuitry of this density. For planning metrology requirements during this time frame, a chip density parameter value of 10^7 to 10^8 bits/in^2 will have to be measured.

FIGURE A-5
Trend Curve for
LSI Circuit Density



A.2.3.3 Chip Complexity (Gates/Chip)

Larger chip sizes coupled with greater circuit density produce LSI chips with more components. Figure A-6 shows the trends in chip complexity in terms of gates per chip. Before 1980, it will be possible to place up to 100,000 gates on a single NMOS or PMOS chip. Future CCD chips may contain a million gates. In the future, chip complexity will be limited primarily by the market for such complex electronics, rather than by technology. The level of functional capacity afforded by advancing LSI technology will exceed user requirements by the year 2000. It is expected that resources will not be expended in advancing the state-of-the-art much beyond the 1980 achievement levels.

The complexity of a chip is governed by three factors:

- Dimension reduction
- Die and wafer size
- Device and circuit cleverness.

Device dimensions are expected to decrease at their present rate of 0.62 μm per year. The contribution from increased wafer size is also expected to grow at the present rate, doubling every 16 months. The contribution from circuit or device cleverness is expected to taper off as theoretical limits dictated by the atomic structure of matter are approached. However, new technical approaches governed by different physical laws may act to drive this upper limit well beyond the 1/4 billion functions per chip predicted for current approaches.

A.2.3.4 Function Cost (Cents/Bit)

Since manufacturing costs are determined primarily by material costs, the increasing densities of LSI devices result in decreasing cost per function. A slight increase in manufacturing costs resulting from increased circuit density is offset by an increase in manufacturing yield. Figure A-7 indicates the trends in LSI function cost. NMOS and PMOS are the cheapest devices, and will remain cheaper than bipolar and CMOS. Cost estimates for CMOS/SOS chips were unavailable; however, the sapphire substrate costs 10 times more than silicon. If, as predicted, SOS yields are higher than MOS, this cost difference can be reduced or even eliminated. CMOS and CCD costs are decreasing very rapidly because these are relatively new technologies and rapid improvements can be expected. Eventually, CCD costs will drop until they are less than PMOS/NMOS costs by a factor of five or more.

FIGURE A-6
Trend Curve for
LSI Chip Complexity

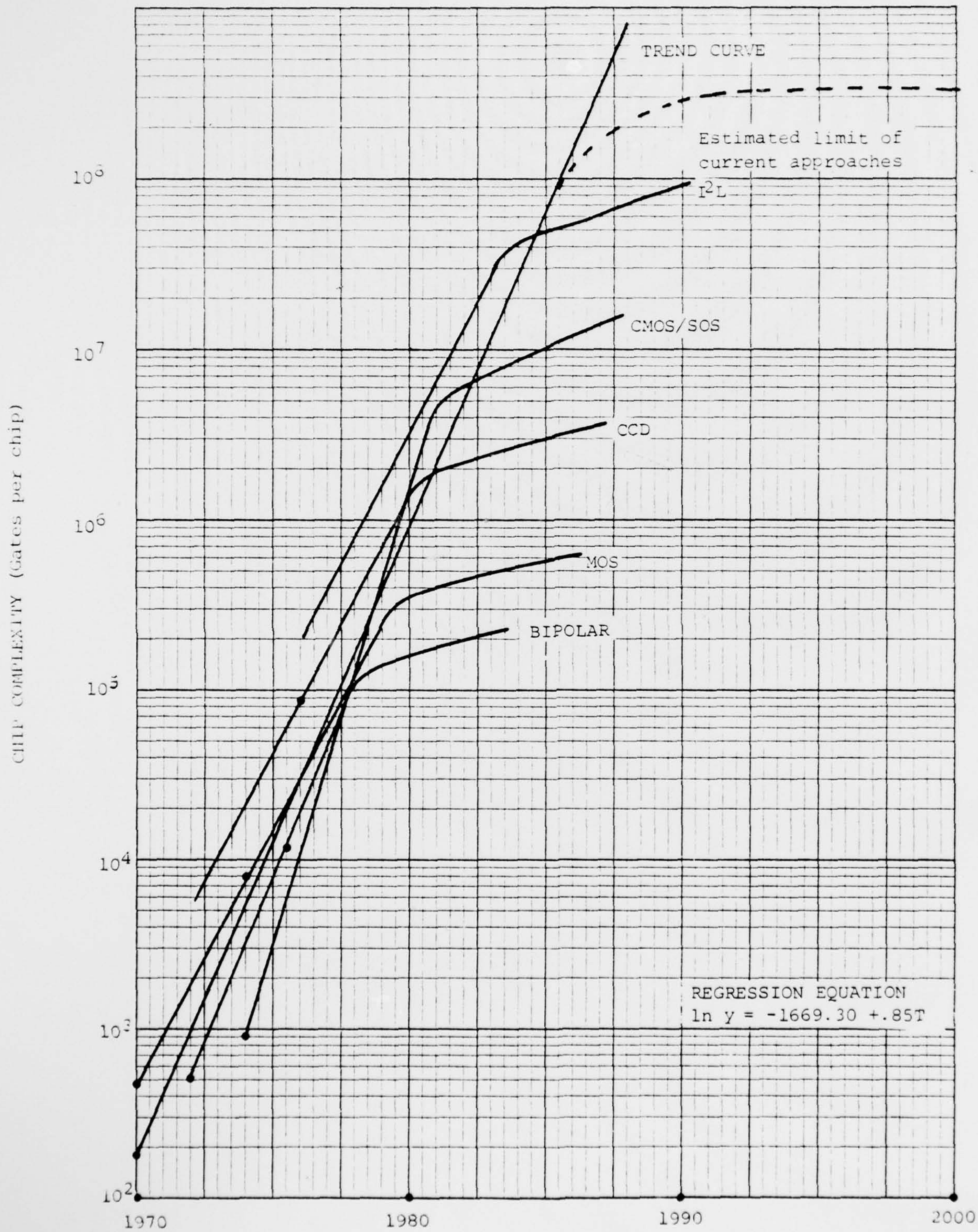
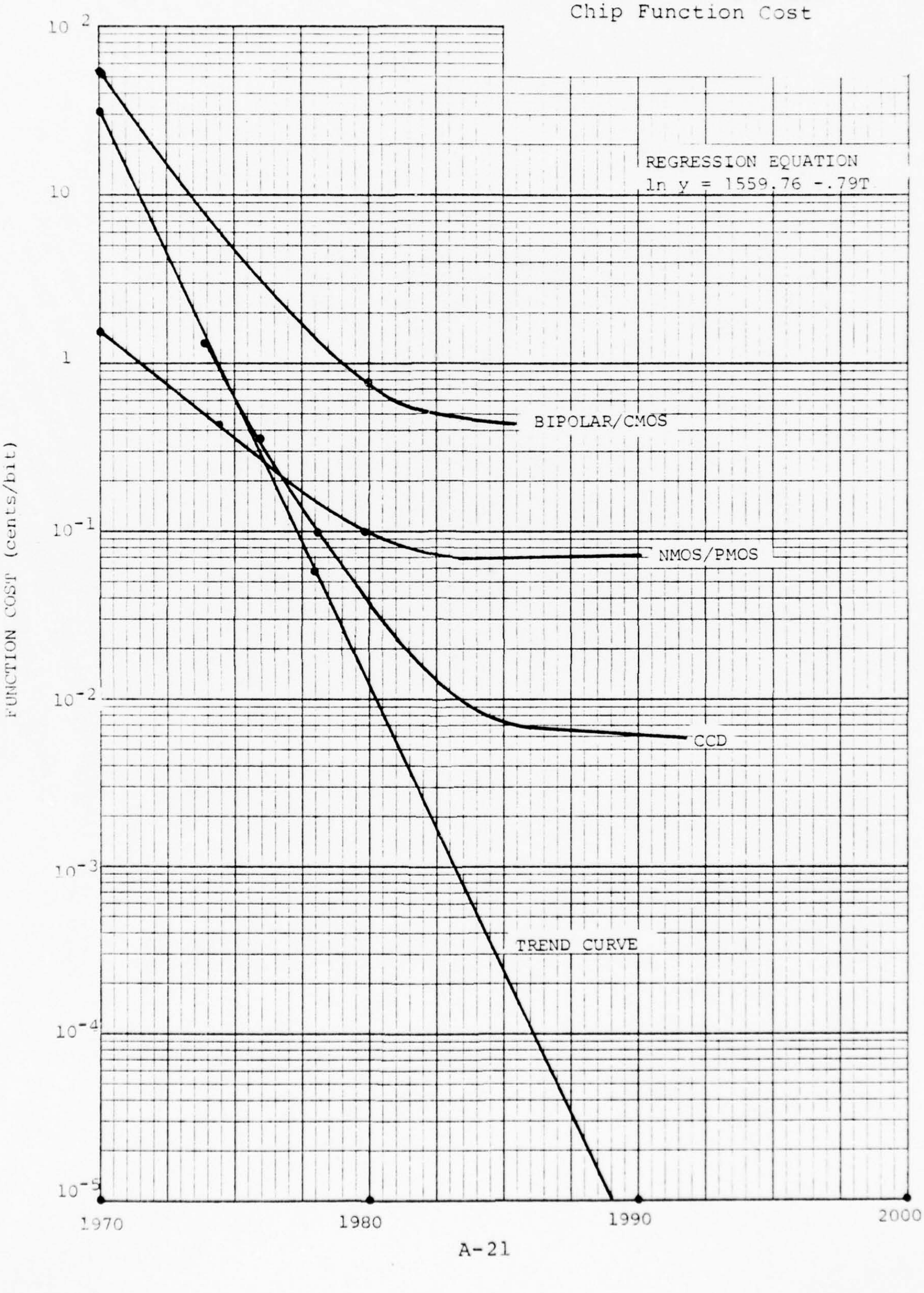


FIGURE A-7
Trend Curve for LSI
Chip Function Cost



A.2.3.5 Power Consumption (Milliwatts/Bit)

Figure A-8 shows power consumption trends for relatively low-speed (1 to 10 MHz) circuitry. CMOS and CMOS/SOS use very little power in the standby mode. CCD devices have inherently low power consumption, even at relatively high speeds.

The reduction in power consumption can be expected to result in equipment cost savings of millions of dollars based on cost reductions anticipated in the number or capacity of primary and secondary batteries used for power sources alone.

The ECOM long-range goal (circa 1985) for linear IC power consumption for use in portable communications equipment is an order of magnitude reduction from 1974 power levels.

A.2.4 Digital Voice Coding

A.2.4.1 General

Digital transmission has an inherent advantage over analog transmission. The digital signal can be regenerated with a very low error rate and almost no distortion. An analog repeater always adds some noise to the signal, hence the total transmission length is limited by the receiver signal-to-noise ratio. The regenerative properties of digital signals can be used to advantage in reducing crosstalk and interference. Digital signals also lend themselves to security coding techniques.

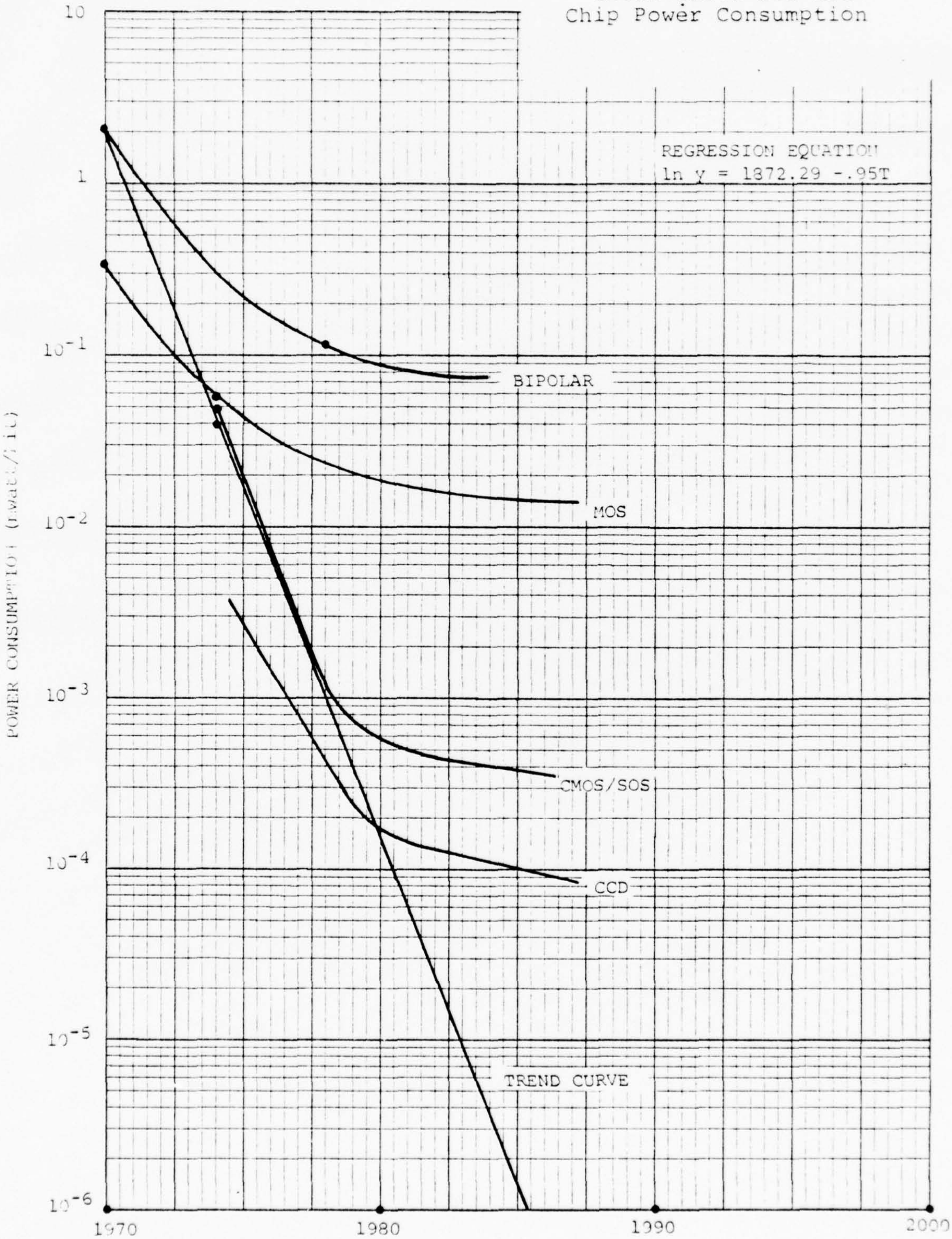
For voice transmission, these advantages are partially offset by the increase in bandwidth required for transmission. Two basic methods exist for transforming analog voice signals to digital signals:

- To provide a digital representation of the analog waveform (e.g., PCM, CVSD)

- To extract the intelligence from the waveform and transmit only that portion (e.g., vocoders, linear predictive coding).

Great promise for bandwidth reduction exists in the second method. Theoretical considerations indicate that a transmission rate of less than 100 b/s is all that is necessary for the human voice. However, gains achieved by eliminating all redundant data from the waveform would be offset by the error control which would then be required. Transmissions

FIGURE A-8
Trend Curve for LSI
Chip Power Consumption



of other parameters to achieve high voice quality and recognition would require more bandwidth than would transmission of just the basic information.

Recent progress in the reduction of bandwidth is occurring because of two parallel developments: advances in coding techniques and advances in LSI technology. In the former area, pulse code modulation (PCM) and continously variable slope delta (CVSD) modulation techniques currently in use will give way to analysis/synthesis techniques such as linear predictive coding. Analysis/synthesis uses prediction algorithms which require relatively sophisticated digital processing. Current equipment is correspondingly large. Advances made in LSI technology and the advent of microcomputer chips will allow analysis/synthesis equipment to be smaller, lighter, cheaper, and less power consuming.

Vocoders are currently in use and have been used for some time. They presently operate at bit rates as low as 2400 b/s. They achieveing only poor voice quality, hence, speaker recognition is poor. Research is continuing, however, and they will be competing with linear predictive encoders for use in military communication systems in the 1980s.

A.2.4.2 Forecasts

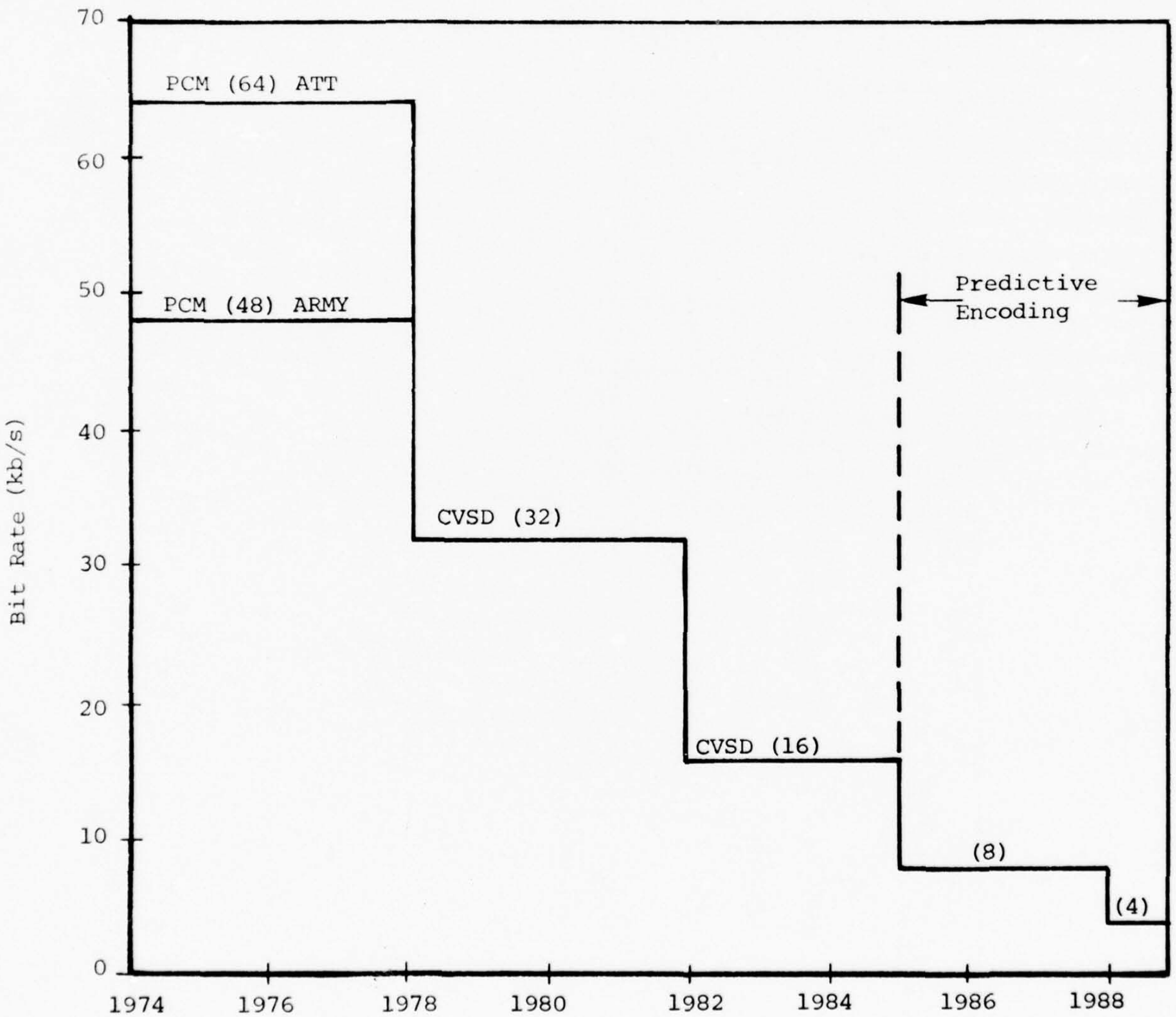
Figure A-9 shows projected bit rates for military digital voice communications systems. Digital voice coding schemes operating at bit rates as low as 2400 b/s have already been satisfactorily demonstrated in the laboratory. However, their performance is unproven in a real communications environment. Current equipment is the size of a standard minicomputer, whereas practical operation requires a smaller, cheaper processor. The rapid advance of LSI technology will aid in reducing processor size.

Estimates of the date of availability for practical devices vary widely. Table A-3 gives cost, power, and estimated availability dates for laboratory prototypes of single-channel digital voice coders using predictive encoding with various output bit rates. Voice quality will vary, but the 1980 versions should be equivalent to earlier versions at twice the bit rate. The cost figure includes only the analog/digital conversion components. These versions will eventually appear operationally in military communications systems (see Figure A-9).

TABLE A-3
Future of Digital Voice Coding

Date of First Production	Bit Rate (b/s)	Number/Type Chips	Power Consumption (Watts)	Cost/Subscriber ($)
1974	8000	200 Bipolar MSI	20	3,000
1976-78	8000	15-20 CMOS LSI	1-3	1,000
1974-76	4000	200 MOS MSI	10	3,000
1980	4000	20-25 CMOS/SOS LSI	5	1,000
1980	2000	20-25 CMOS/SOS LSI	5	1,000

FIGURE A-9
Predicted Lowest Voice Bit Rate
for Operational Systems



A.2.5 Solid-State RF Generators

A.2.5.1 General

By the 1985-2000 time frame, solid-state RF generators will have replaced such tube-type devices as the klystron and traveling wave tube for most applications. The types of solid-state devices available are transistors and two-terminal devices. Figure A-10 indicates the practical frequency range of these devices.

Transistors are of two types: field-effect and bipolar (junction). There are two types of two-terminal devices: those using transferred electron effects, and those using avalanche effects.

Trend curves were not prepared for this section because current technological approaches to solid-state RF generators are at or near theoretical limits. New solutions to micro- and millimeter wave generating devices are coming from other technology areas (e.g., masers which are an extension of lasers down into the microwave spectrum, and sophisticated techniques using gas plasmas). The forecast is thus narrative, with examples of current technology performance provided.

A.2.5.2 Bipolar Devices

Bipolar transistors are presently limited to operation below 4 GHz. This should be extended to 6 or even 8 GHz by 1980. Since the average power output of a transistor varies inversely with the square of the operating frequency, it is useful to define a performance parameter of watts-GHz^2. In 1966, the average value of the parameter was 5 watts-GHz^2; today, it is 100 watts-GHz^2. The estimated theoretical limit is 2400 watts-GHz^2. Figure A-11 plots the trends in this parameter. The ECOM long-range objective (circa 1985) for UHF transistor power is a 40-time increase from 1974 levels. Performance trends indicate that this achievement is possible. Typical 1974 and anticipated 1980 bipolar transistor characteristics are as follows:

	1974	1975
Maximum operating frequency (GHz)	4	6-8
Maximum power output (average watts) (at maximum frequency)	5	6-8
Efficiency (at maximum frequency)	30%	40%

FIGURE A-10
Frequency Ranges of Solid-State
RF Devices (1976 and 1980)

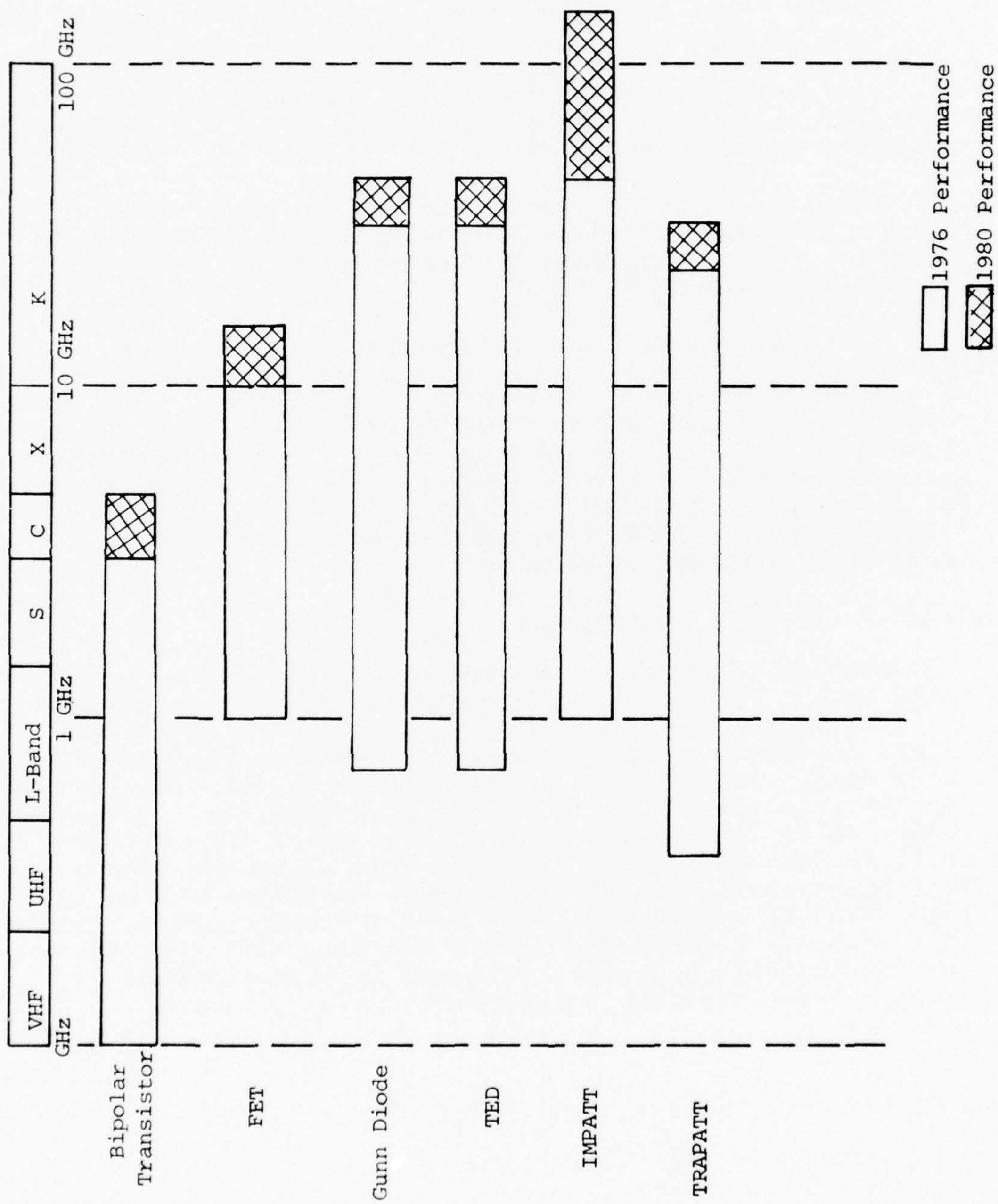
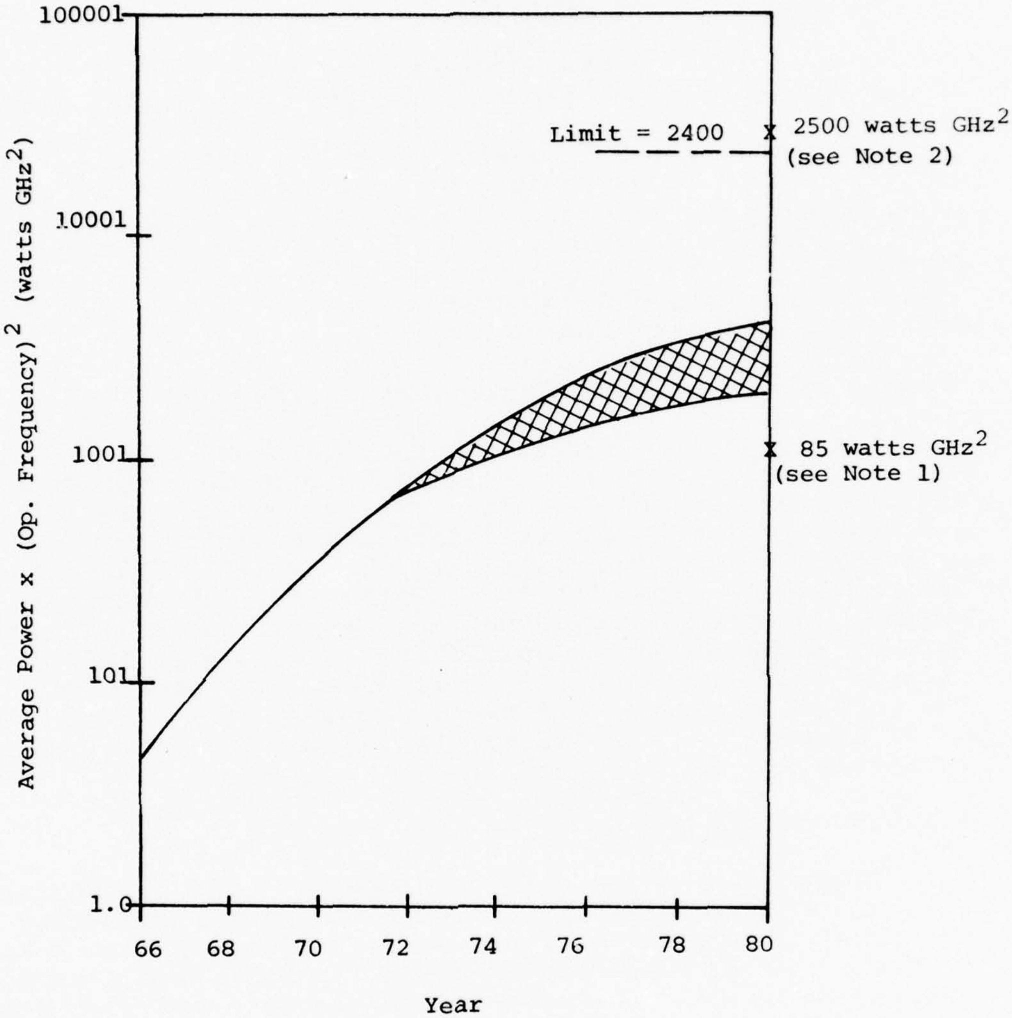


FIGURE A-11
Power Transistor
Performance Parameter



Notes: 1) Power transistor development for AN/GRC-103

(a) 25 watts
(b) 10 dB gain
(c) 1.35 - 1.85 GHz
(d) 60% collector efficiency (see Figure A-12)

2) Power transistor requirement for AN/GRC-144

(a) 100 watts
(b) 4.5 - 5.0 GHz

A.2.5.3 Field-Effect Transistors

Because of its compact geometry, the field-effect transistor (FET) can operate efficiently at higher frequencies than bipolar transistors. As shown in Figure A-10, their current operative limit (which is below 10 GHz) will be extended to 15 GHz by 1980. At 15 GHz, a power FET should provide a 1-watt output with a 35-percent efficiency. The power frequency parameter of this transistor would be 225 watts-GHz^2. FETs are expected to find limited application in transmitters and considerable application in microwave and millimeter-wave receivers.

A.2.5.4 Gunn and Transferred Electron Devices

Gunns and transferred electron devices (TED) are the simplest solid-state microwave and millimeter wave devices and,therefore, their technology is the most mature. They are quieter than impact avalanche and transit time (IMPATT) or trapped plasma and avalanche transit time (TRAPATT) devices but operate with lower efficiency and output power. In transmitters, they can be used as oscillators driving an IMPATT power amplifier. Gunn diodes and TEDs will be used extensively in millimeter-wave receivers. The present power and efficiency are shown in Figure A-12. Because the technology, is mature, great performance increases are not expected.

A.2.5.5 IMPATT Diodes

IMPATT diodes are capable of higher output power and greater efficiency at higher operating frequencies than previously discussed devices. They are noiser than transistors or TEDs, but quieter than TRAPATTs. IMPATTs are a good compromise between low-power, quiet devices and high-power, noisey devices. They are capable of reasonable output power at millimeter frequencies (i.e., 1 watt at 10-100 GHz). Figure A-13 shows the power achieved by several devices (shown as dots) as a function of frequency. The dashed line indicates the calculated thermal limits to IMPATT output power. As can be seen from the figure, operation below 10 and above 60 GHz is already near theoretical limits. Improvements can be made in the 10-60 GHz range and it is likely this will be achieved by 1980.

FIGURE A-12
Performance of Gunn and
Transferred Electron Devices

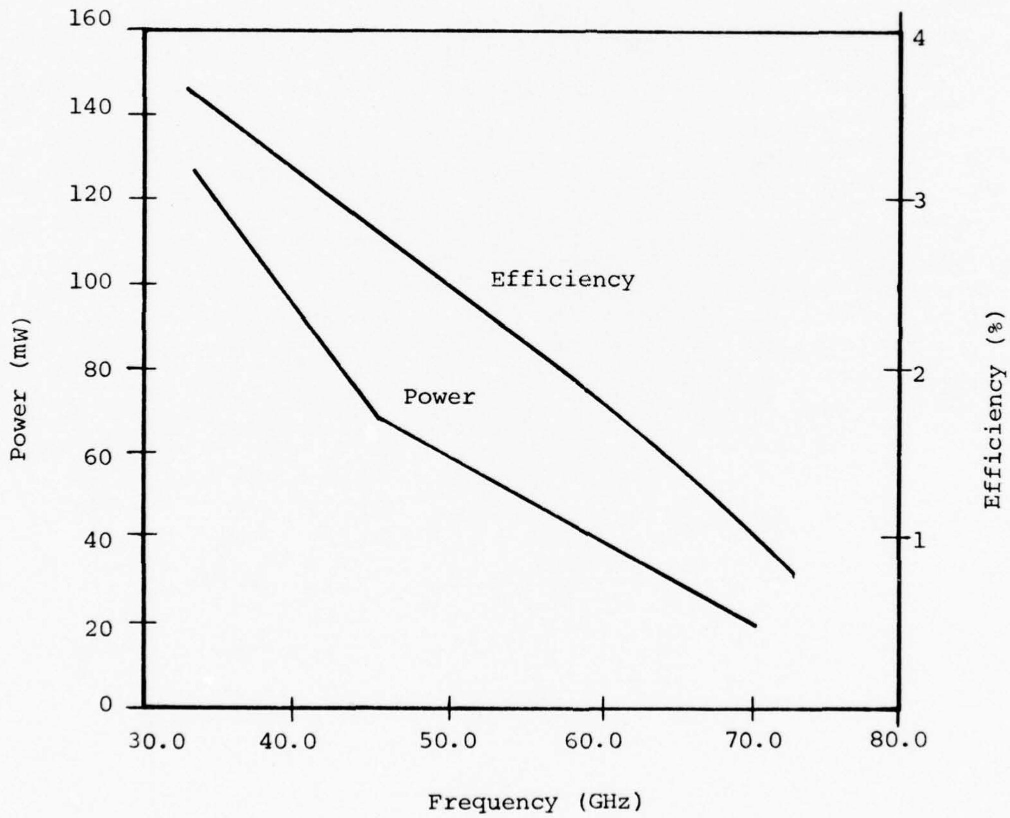
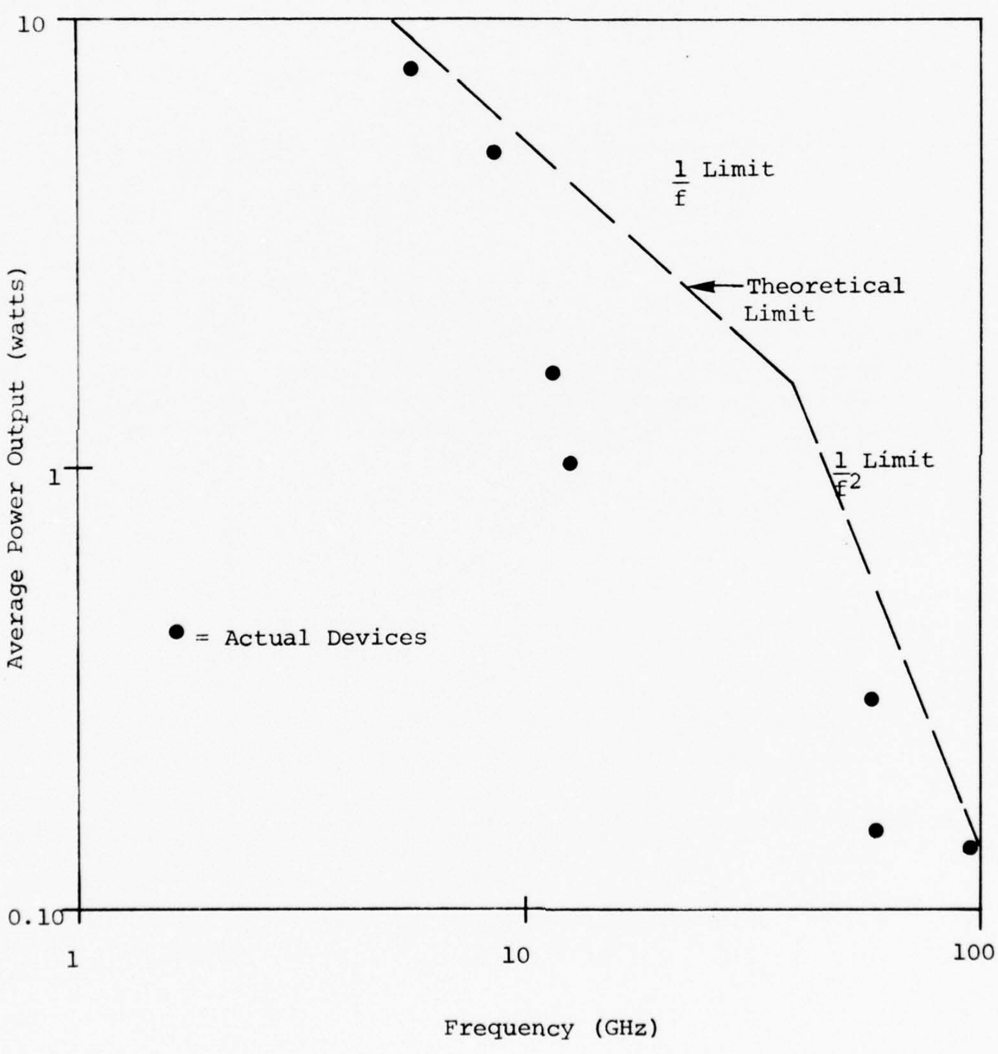


FIGURE A-13
Average Power Versus Operating
Frequency of IMPATTs



IMPATT diodes are expected to become significantly more efficient. Figure A-14 shows efficiency versus operating frequency for present and future devices. The large improvement in efficiency is a result of the read-type IMPATT diode. Experimental models of these have already demonstrated the efficiency shown. Practical read-type IMPATTS will be produced by 1980.

A.2.5.6 TRAPATT Diodes

The TRAPATT diode is a high-power, high-efficiency device. A maximum pulsed power of 1.2 kW has been achieved at 1.1 GHz with five diodes in series. The power and efficiency of several TRAPATT diodes are plotted in Figure A-15.

Peak power outputs range from hundreds of watts at L-band (0.4-1.5 GHz) to tenths of a watt at X-band (5.2-8.5 GHz). Typical efficiencies are 60 percent at L-band and 30 percent at X-band. TRAPATT amplifiers provide much higher pulsed-power outputs than any other type of diode microwave amplifier. However, they are highly non-linear and have very poor noise figures. Bandwidths achievable are also narrow. Because of these limitations, TRAPATT diodes are not expected to find much use in communications systems.

A.2.5.7 Barrier Injection Transmit Time Devices

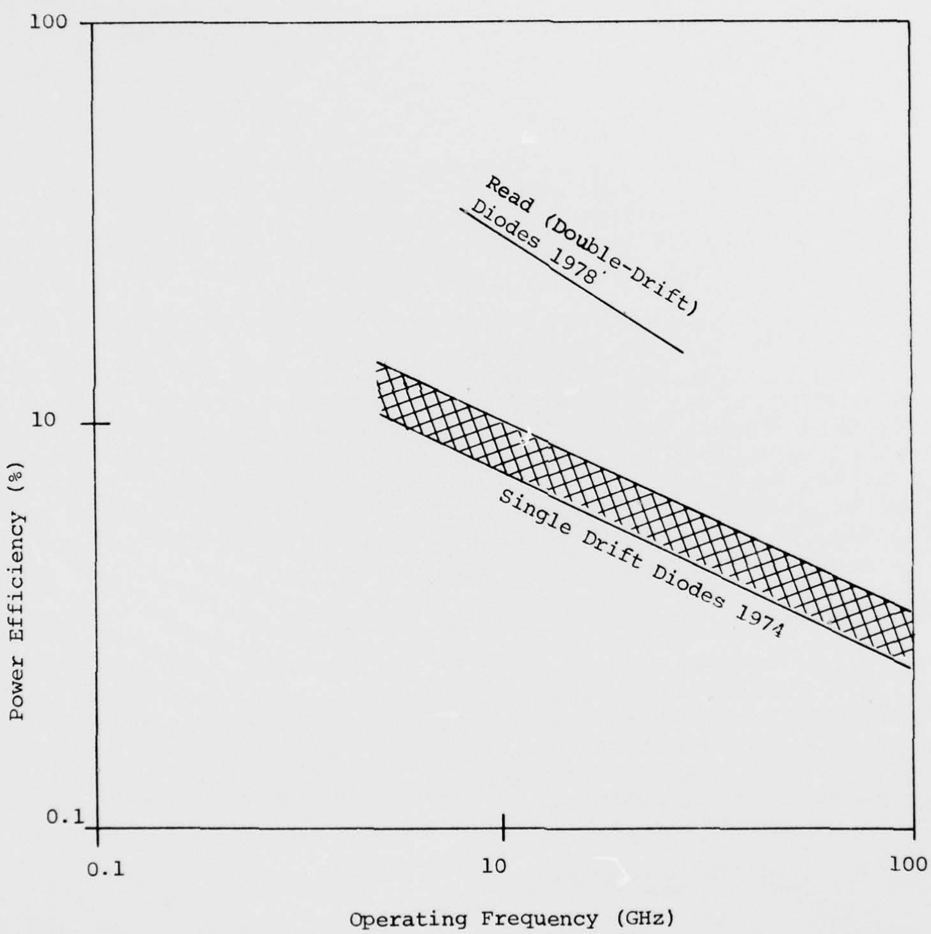
Barrier injection transit time (BARITT) devices are the newest of the active microwave devices but potentially the most cost- and performance-effective. They are quieter than IMPATTs and easily fabricated using silicon technology, but they are limited in output power and bandwidth. Further research is needed to evaluate the potential of BARITTs for future applications.

A.2.6 Optical Communications

A.2.6.1 General

With the advent of advances in laser technology, low-loss optical fibers, semiconductor optical sources and detectors, and electro-optic signal devices, optical communications is now a practical goal. Bandwidths from 100 MHz to over 1 GHz are possible. Optical communications can be established either over an atmospheric path or

FIGURE A-14
IMPATT Power Efficiency
Versus Operating Efficiency



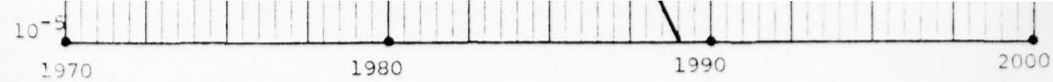
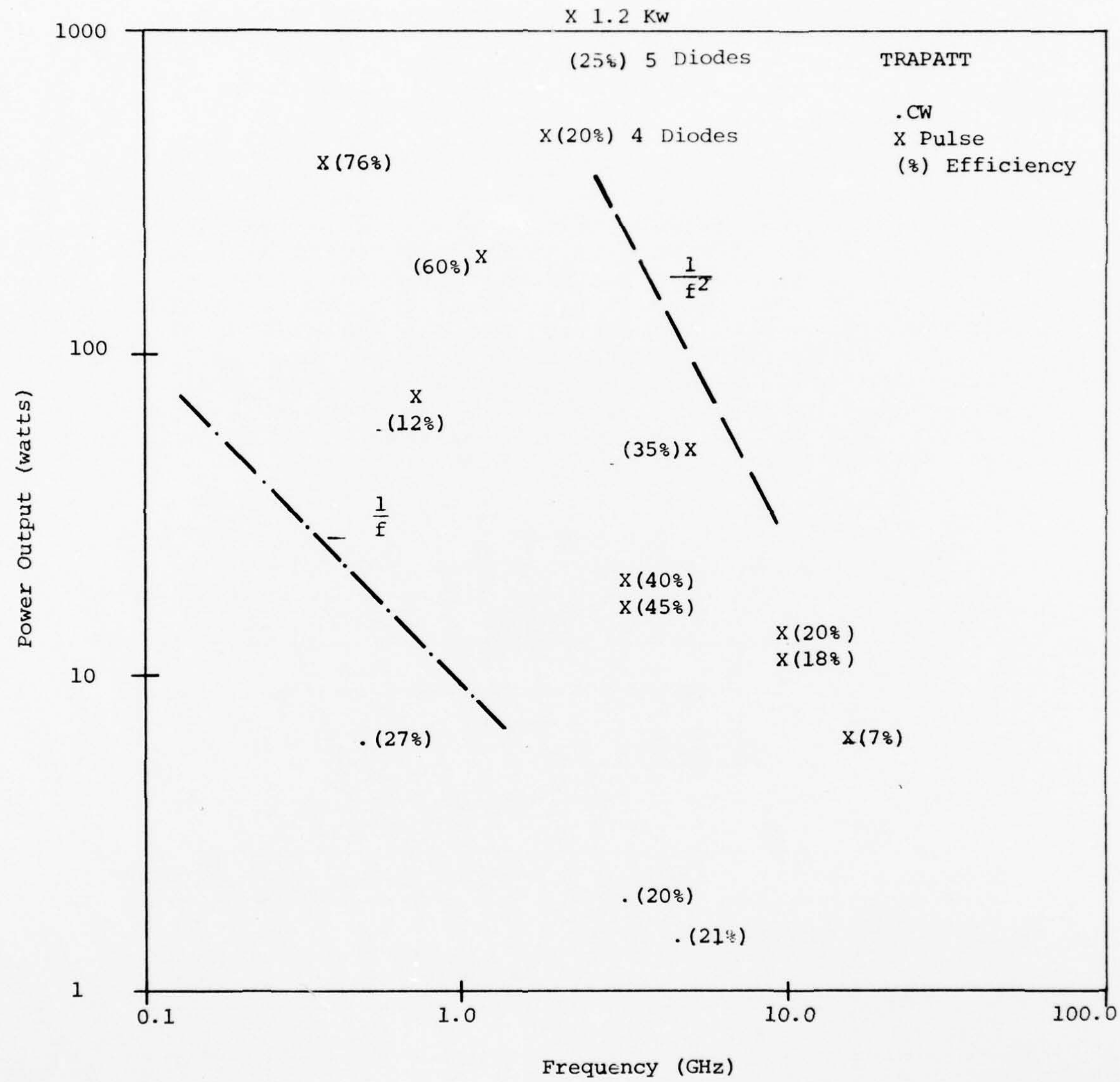


FIGURE A-15
State-of-the-Art Power Versus
Frequency, for TRAPATT Diodes



through fiber optics transmission lines. The former method requires high-power laser transmitters, the latter some type of drive mechanism which could be a laser or an LED.

A.2.6.2 Lasers

Problems associated with using lasers for communications applications have included low duty cycle operation permitting only a limited information rate, and low performance detectors. Recent advances in technology have made laser communications a practical alternative. These advances include: high average power gas lasers (CO, CO_2); solid-state lasers; electro-optic modulators; silicon avalanche photodiode detectors; HgCdTe far-infrared detectors; and infrared-sensitive photomultipliers. Several experimental military systems are presently being built or tested. These may well be in field use in 3 years. Table A-4 indicates the performance of two systems being developed by ECOM.

TABLE A-4
ECOM Laser Communications System Developments

Bit Rate	200 kb/s	5 Mb/s
Wavelength(μm)	0.904	10.6
Laser	Gas solid-state	CO_2 gas
Bit Error Rate	10^{-6}	10^{-6}
Range (km)	3	8
Receiver	Avalanche photodiode	Optical heterodyning
Power Consumption(W)	10	600
Weight (lbs.)	10	121
Size (inches)	7x7x7½	25x30x6

Newer laser technology will allow systems to be much smaller without sacrificing performance. Present and 1980 versions of the 5-Mb/s system are as follows:

	Present	1980
Size (inches)	25x30x12	10x10x12
Weight (lbs.)	120	60
Power Consumption (W)	600	200

Practical methods for stabilizing laser mounting platforms to minimize misalignment, plus improved output power and bandwidth, will be available by 1980.

Another important area will be tunable infrared (IR) lasers. Since atmospheric absorbtion fluctuates over a wide range with small changes in wavelength, a tunable laser could be tuned to the wavelength of minimum absorption for the time of transmission. These systems would use either CO or CO_2 excited Raman resonator lasers. Projected performance of these systems is listed in Table A-5.

Table A-5
Post-1980 Tunable IR

Parameters	CO Laser	CO_2 Laser
Input Excitation	2.5 w	10 kW
Output Tuning Range (μm)	5.4-6.2	10-11
Output Power	1 w	1 kW
Frequency Stability (Hz)	1	1

A.2.6.3 Fiber Optics

An optical fiber is a thin filament of optically transparent material which conducts light energy along the length of the filament. Optical fibers typically have a central core surrounded by a cladding of material with a lower index of refraction through the core. This tends to keep the light energy confined to this core. Because fibers have a tendency to break, a fiber optics cable consisting of several individual fibers is often used. This is advantageous in interfacing with a light source which is typically larger than 3 mils. Many fibers in a cable cause problems as a result of modal dispersion and differential fiber length.

Light propagating through the various possible paths in the multiplier cable produces transverse interference patterns which produce optical modes. The optical modes have different group velocities and thus cause a pulse transmitted through the cable to become broadened as a result of the late arrival of light energy from modes with slower group velocities. This effect is known as modal dispersion. The pulse broadening effect reduces the information capacity of the cable. The differing lengths of the fibers comprising the cable result in different lengths of propagation paths for the signal, again causing interference which reduces capacity.

Use of a single small fiber with only one propagation mode eliminates these problems. However, coupling to the fiber is a severe problem. Cable designs are being developed which substantially reduce modal dispersion by using graded-index fibers. These serve to continually refocus the energy along the fiber core. Great reductions in impurity levels have also been achieved. This, coupled with improved light sources, modulators, and detectors has made fiber optics communications practical.

Despite the current relatively high cost of fiber optics cable systems, they have unique properties of significant benefit to military communications systems. While laser beams are difficult to intercept, fiber optics cables offer more security because of ease of detection of attempted fiber penetration. Also, there no signal leakage is detectable outside the cable jacket.

Fiber optics are better than lasers because line-of-sight visual contact is unnecessary and they are not affected by atmospheric attenuation. The advantages of fiber optics systems over electrical transmission lines are:

- Electromagnetic interference and crosstalk immunity
- Security - no signal radiation from fibers
- Electrical isolation of transmitter and receiver
- Large bandwidth
- Small diameter and weight
- High temperature tolerance (500-1000°C)
- Nuclear radiation resistance.

The disadvantages of fiber optics systems over electrical transmission lines are:

- High cost of low-loss fiber optics cables
- Present higher cost of terminals
- Tendency of fibers to break.

Progress is being made in reducing attenuation. The improvement trend in state-of-the-art single-fiber optical cables is shown in Figure A-16. The theoretical limit resulting from intrinsic (molecular) scattering is shown in Figure A-17. As indicated in the figure, this limit varies with wavelength. Laboratory model optical fibers have already approached the theoretical limit of attenuation. Future improvements appear to be in cost rather than in decreased attenuation for these high-performance fibers. Low-loss fibers can be expected to decrease in cost by a factor of four or more by 1978. Optical cables can be expected to replace 26-pair and PCM cables by 1980. Figure A-18 indicates cost-reduction projections for low-loss fiber optics cables. Costs of these cables in 1985 will largely determine the inventory of fiber optics cable in the year 2000.

The development of practical fiber optics communications systems is also dependent on optical terminals, which provide the necessary conversion of the signal energy into light for transmission through the optical cables. In the first fiber optics systems, discrete components will be used but these will be quickly replaced with integrated optics which will provide single-mode optical waveguides, optical switching, signal multiplexing, and network couplers. The devices involved in the forecast are listed in Table A-6.

TABLE A-6
Devices for Fiber Optics Communication

Light Sources
. LEDs
. Semiconductor injection lasers
. Other lasers
Light Detectors
. Silicon photodiode (PIN) detectors
. Silicon avalanche photodiodes
. Photomultipliers
Integrated Optics Functions
. Switching
. Coupling
. Multiplexing
. Modulation.

FIGURE A-16
Attenuation Versus Year
for Optical Fiber

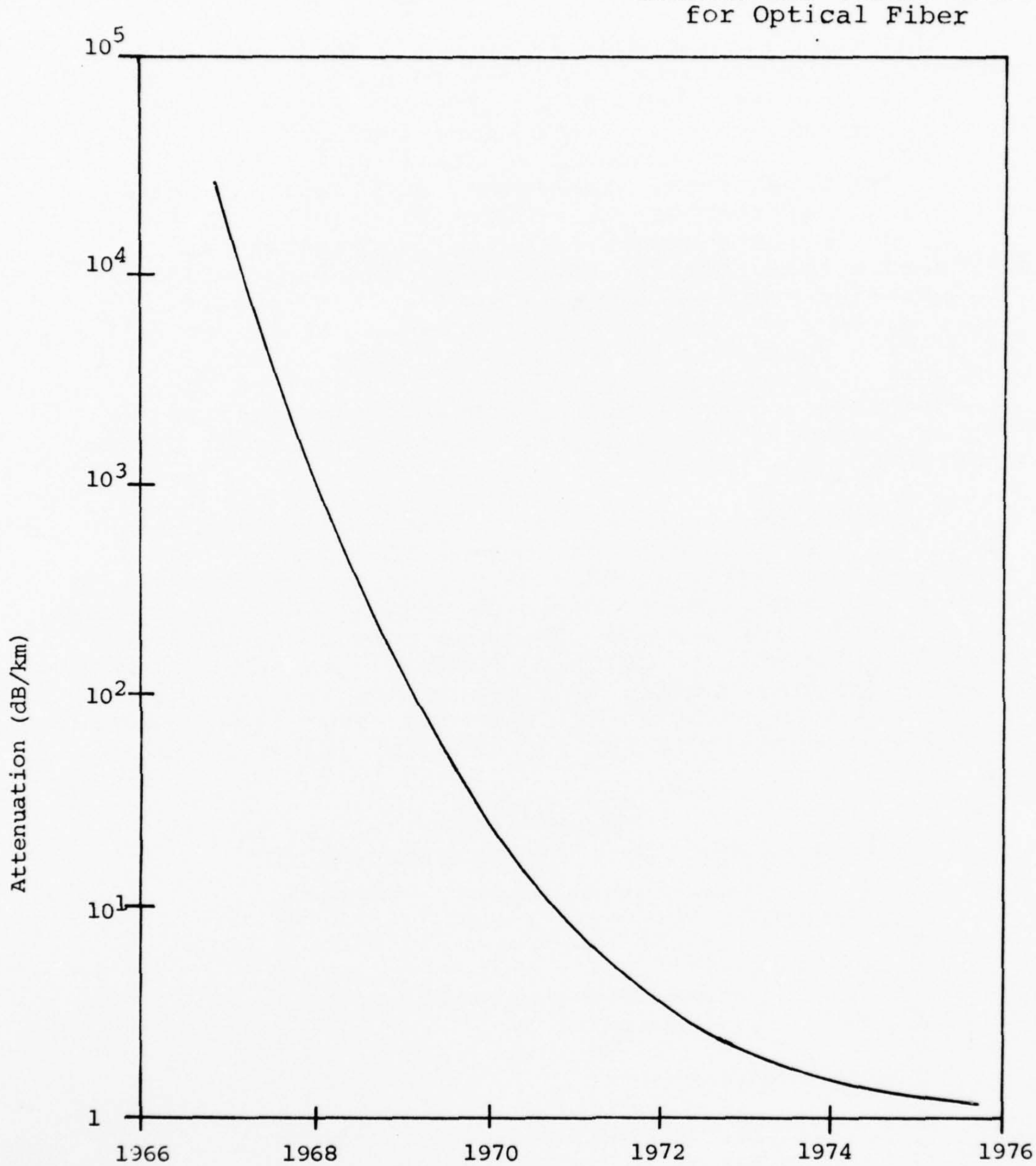
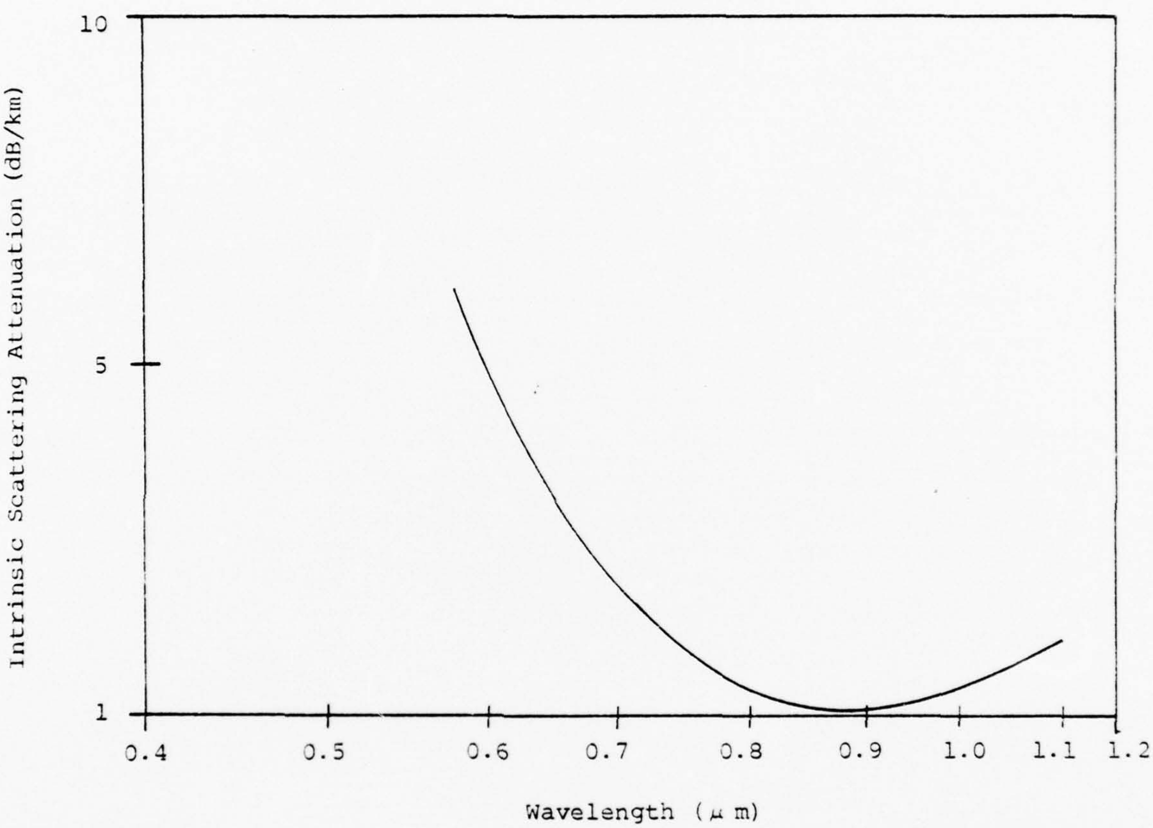


FIGURE A-17
Fiber Optics Minimum
Attenuation Versus Wavelength



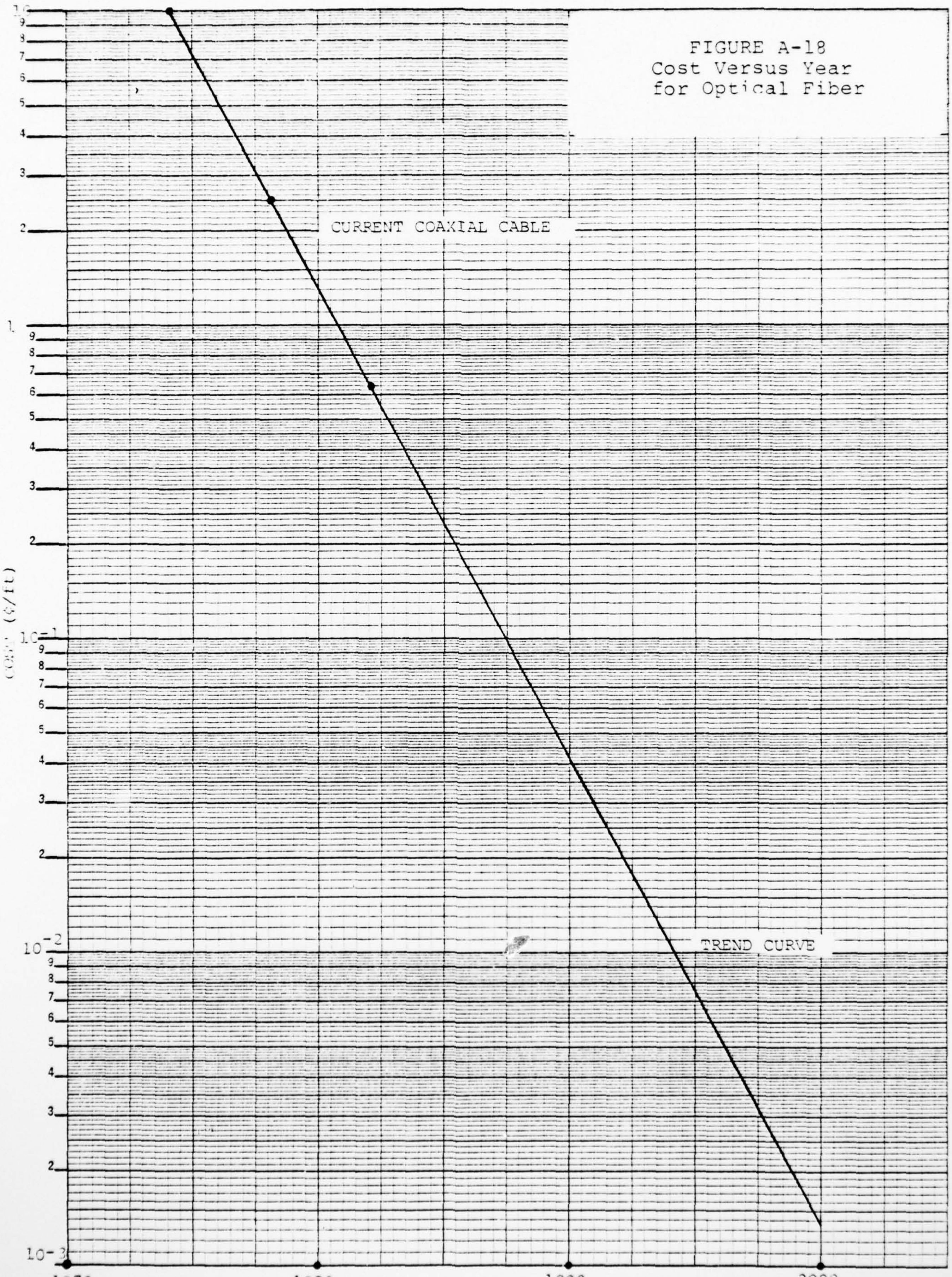


FIGURE A-18
Cost Versus Year
for Optical Fiber

LEDs were used initially for light sources in fiber optics communications systems. LEDs are readily available and are very reliable. Output light intensity varies linearly with driving current making LED light sources easy to modulate. However, efficient coupling to optical cables is impossible because of the wide emission angles of LEDs, and is a serious disadvantage. This limits the information rate achievable. Present technology has reached a bandwidth of about 200 MHz, although 50 to 100 MHz is more common. Characteristics of commerically available LEDs are listed in Table A-7.

TABLE A-7
Range of Characteristics of Commercially Available LEDs

Characteristic	Range
Light Output Power (mW)	0.3 to 40
Peak Wavelength (m)	0.9 to 0.93
Spectral Halfwidth (m)	0.04 to 0.05
Rise Time (ns)	1 to 300
Price ($)	5 to 400
Efficiency (%)	Typically 10
Mean Time Between Failures	Very long (i.e., many years)
Maximum Modulation Rate (MHz)	1 to 200

LED performance is not expected to improve greatly. Prices will be dropping significantly as the production volume of LEDs increases. The availability, reliability, relatively low cost, and small size of LEDs will keep them in a significant role in fiber optics communications for many years. Their low information rate capabilities, however, will eventually cause other devices, their replacement by particularly semiconductor lasers.

The coherent properties of laser emisssion solve some of the coupling and information rate problems of LEDs. The problems which must be solved with semiconductor lasers are low duty cycle operation and the need for cryogenic cooling. Experimental room-temperature semiconductor lasers have been operated in a continuous mode. Practical versions of these laboratory models will be produced by 1978. Table A-8 gives the characteristics of these laboratory lasers.

TABLE A-8
Laser Sources for Fiber Optics Communication

Type	Maximum Data Rate (Mb/s)	CW Output Power (watts)
Injection	5-100	15
CS Injection	1000	0.1
Mode-Locked ND: YAG	500	0.175

Detectors for fiber optics that show promise are silicon PIN photodiodes, silicon avalanche photodiodes, and vacuum tube photomultipliers. No dramatic increases in performance are expected for any of these devices. Avalanche photodiodes have internal gain and are thus more sensitive than PIN photodiode but are much more costly. Photomultiplier tubes are also more sensitive and more costly. Table A-9 compares these devices in terms of noise equivalent power, rise time, and price.

TABLE A-9
Characteristics of Fiber Optics Detectors

Type	Noise Equivalent Power (W/Hz)	Rise Time (ns)	Price ($)
PIN Photodiode	10^{-13}	5	5
Avalanche Photodiode	10^{-14}	1	90
Photomultiplier	5×10^{-15}	2.9	400

A.2.6.4 Integrated Optics

Integrated optics are a new development. These use thin-film techniques to deposit optically transparent materials on an opaque substrate. These films are so thin that only a single mode of light propagation is possible. These are essentially optical waveguides. Since less interference is possible with single-mode propagation, information rates can be greatly increased (bandwidths up to 10 GHz). Electrical signals applied to electrodes control the propagation. Besides the obvious applications of sources and detectors, integrated optical circuits (IOC) can be used as modulators, multiplexers, access couplers, and multipole switches. This last function is accomplished using two or more IOC waveguides close together and causing light energy to "switch" from one to the other by applying the proper voltage to the surface electrodes. As an example of this technique, it is expected that a switching network with a 20 x 20 matrix will fit in a 2-cm^2 chip with switching speeds of 1 ns and attenuation of 1 dB/cm. Present and future IOC performance is compared in Table A-10.

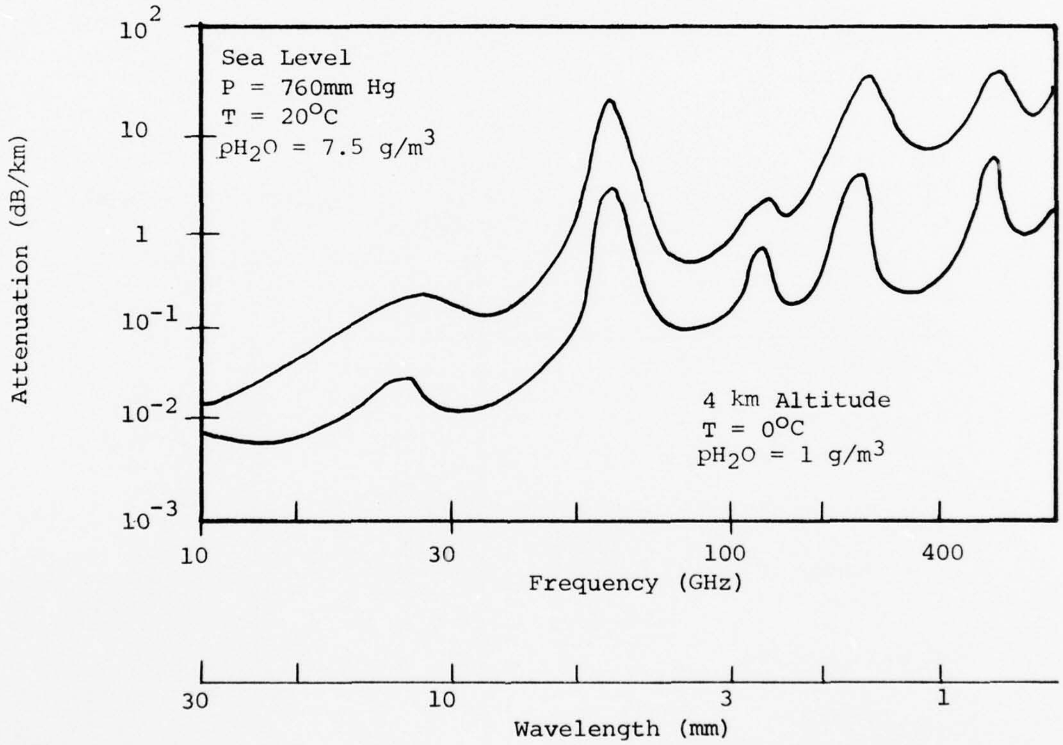
TABLE A-10
Comparison of Present Components Versus Projected IOC Performance

	Present	Projected IOC (1978-1980)
MULTIPOLE SWITCHING		
Speed	10^{-3} sec	10^{-9} sec
Number of Poles	8	128
CARRIER-FREQUENCY MULTIPLEXING		
Number of Frequencies	5	50
Loss	5 dB	0.5 dB
ACCESS COUPLERS		
Loss	3 dB	0.5 dB
Number of Terminals Without Repeater	10	50

A.2.7 Millimeter Wave Systems

An increase in transmission frequency provides an increase in bandwidth and a corresponding increase in channel capacity. Large bandwidths are possible at frequencies having millimeter wavelengths, however, higher attenuation in a clear atmosphere and poor performance in rain dictate relatively close repeater spacing (1-10 km). Figure A-19 shows atmospheric attenuation versus frequency; Figure

FIGURE A-19
Atmospheric Attenuation
of Millimeter Waves



A-20 shows attenuation caused by rain for millimeter wavelengths. The development of components for millimeter wave transmission has lagged behind the development of microwave components. Close repeater spacing is currently uneconomical because of high component cost. Solid-state devices promise to decrease component costs significantly and thus make terrestrial millimeter wave transmission economically feasible. Repeaters will probably consist of a Gunn diode or TED receiver, and an IMPATT transmitter (see Subsection A.2.6). Signal-processing circuitry (such as filters, waveguides, power splitters, circulators, etc.) will be produced using IC technology. This should reduce the cost of components to a fraction of present microwave components.

Satellite communications links can use millimeter wave transmission if frequencies are selected to minimize attenuation effects. Because of the high information rates possible, a relatively small number of transmitters would be needed, thus reducing the cost. Redundant earth stations may be used to reduce the probability of signal loss. High power and high efficiency TWTs that operate in the millimeter wave regions are just becoming available. Costs will be low enough to make millimeter wave communications satellites a reality. The 60-70 GHz portion of the band seems to be primary interest. The ECOM long-range objective (circa 1985) is to reduce millimeter wave transceiver cost by a factor of ten; this objective should be achievable.

Millimeter wave systems are competing with optical systems. Limited funding resources and the desire to obtain maximum use of procured equipments will dictate that millimeter wave equipment produced in 1985 be in use in the year 2000. Similarly, fiber optics systems will be introduced in the 1980-85 time frame and will be in the inventory in the year 2000. The exact proportion of millimeter wave to optical equipment will be determined by procurement actions implemented 20 years earlier. The diversity of the technologies poses a problem in determining future test equipment requirements since all fielded systems must be accommodated.

A.2.8 Mainframe Memories

A.2.8.1 General

The rapid development of solid-state ICs is challenging the standard use of magnetic core memories. The decreasing size, power consumption, and cost afforded by LSI technology has reached the point at which solid-state memory is

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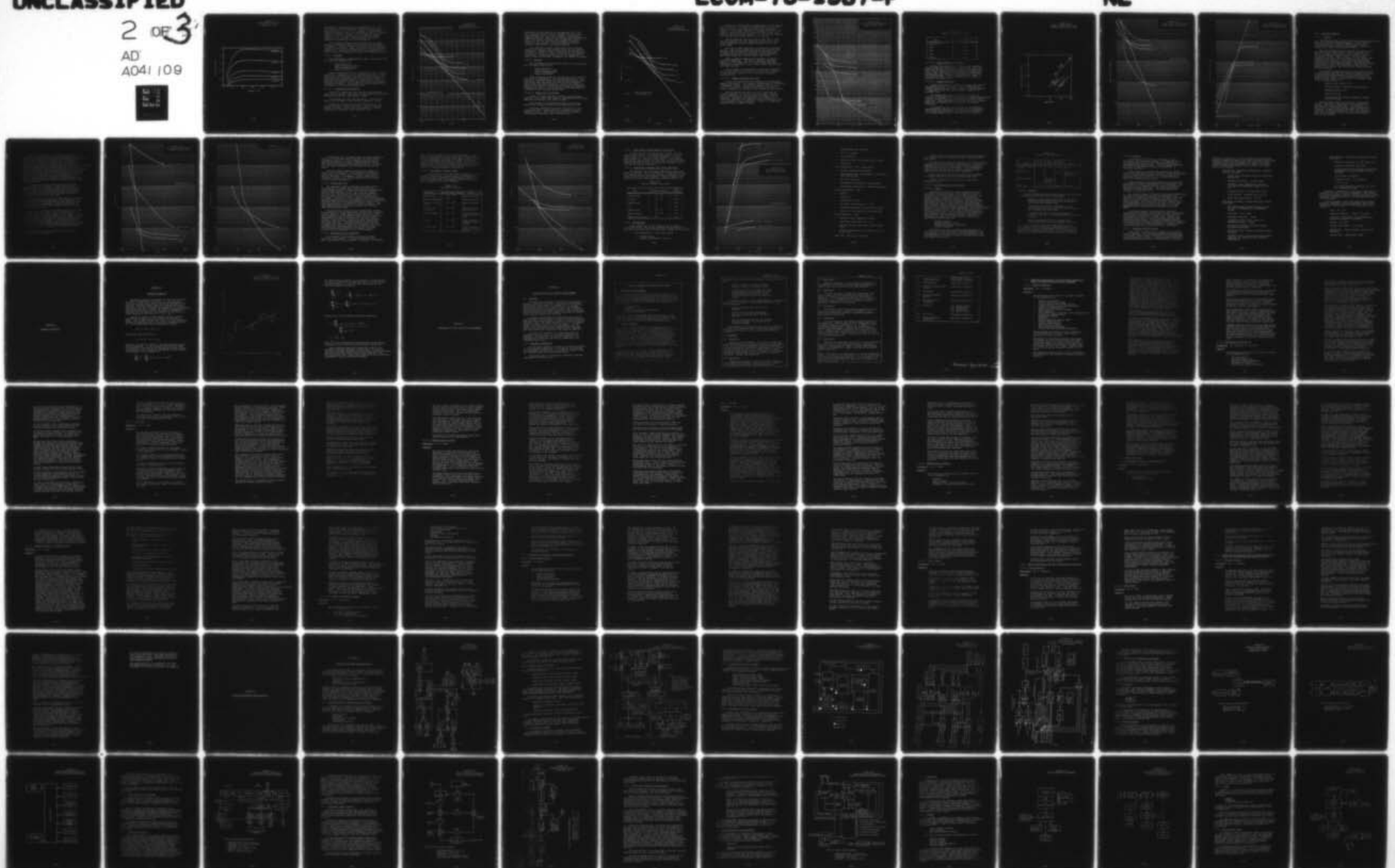

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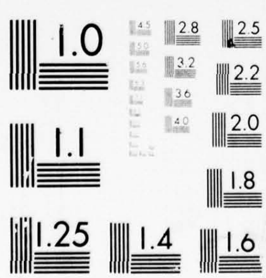
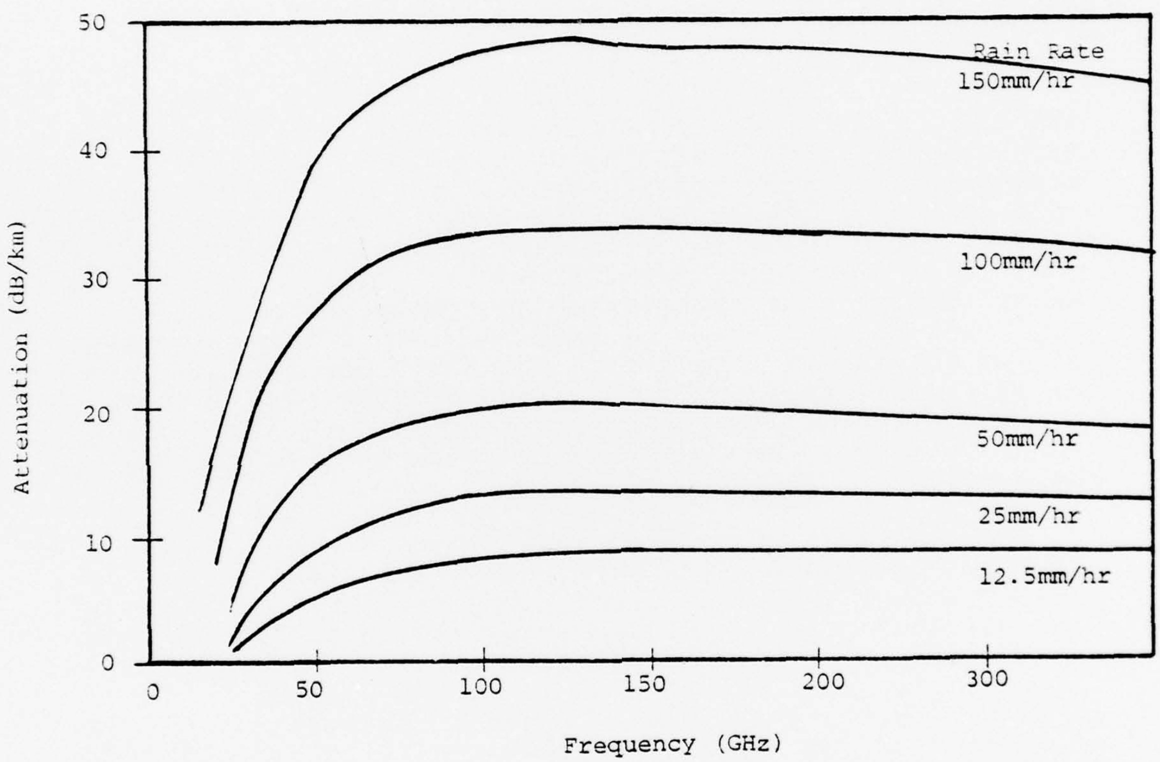


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

FIGURE A-20
Calculated Attenuation
Caused by Rain



preferable to core memories in low-capacity (10^4 - 10^5 bit) applications and is almost competitive with core in large-capacity (10^8 - 10^9 bit) systems. Semiconductor read only memories (ROM) and programmable read only memories (PROM) are finding increasing use in computer systems because of the file security and software maintenance simplicity they provide. ROMs and PROMs are greatly impacting minicomputers and microprocessors.

The classical computer architecture with mainframe memory as a separate, well defined entity in one location is changing. Magnetic memory cores were more economically located in one place in order to share drive and interface electronics. Solid-state memories can be implemented on single chips and dispersed throughout the computer circuitry.

A.2.8.2 Forecast

The performance characteristics used in the projections for mainframe memories are:

- Cost/storage bit
- Access and cycle times
- Power consumption/bit
- Density (bits/in^2).

These characteristics are interrelated; their relative importance is dependent on the intended application. Cost will be an important factor for many applications but more importantly will determine the relative use of magnetic core versus solid-state memories. Access time, power consumption, and density will be important from the standpoint of metrology impact. Projections for these parameters are discussed in the following subsections.

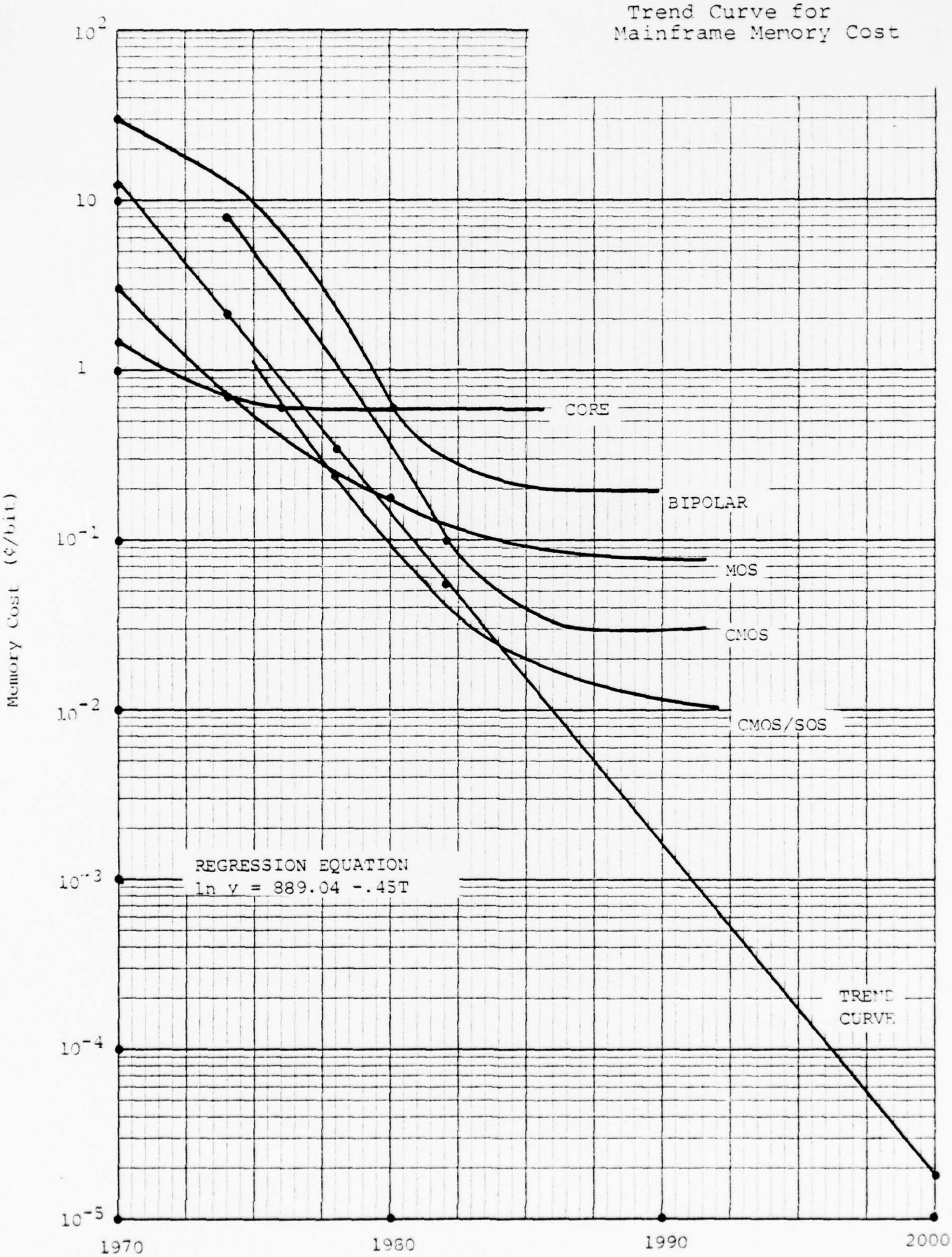
A.2.8.2.1 Memory Cost (Cents/Bit)

Figure A-21 shows the past, present, and projected costs per bit of MOS, CMOS, bipolar, and CMOS/SOS solid-state memories and magnetic core memory systems.

The forecast of continued decreases in solid-state memory cost is based on the relative immaturity of LSI.

Presently, manufacturing yields are quite low: 40 percent for small, simple circuits; 5 percent for large, complex circuits. Chip yield is expected to increase significantly producing lower costs per chip.

FIGURE A-21
Trend Curve for
Mainframe Memory Cost



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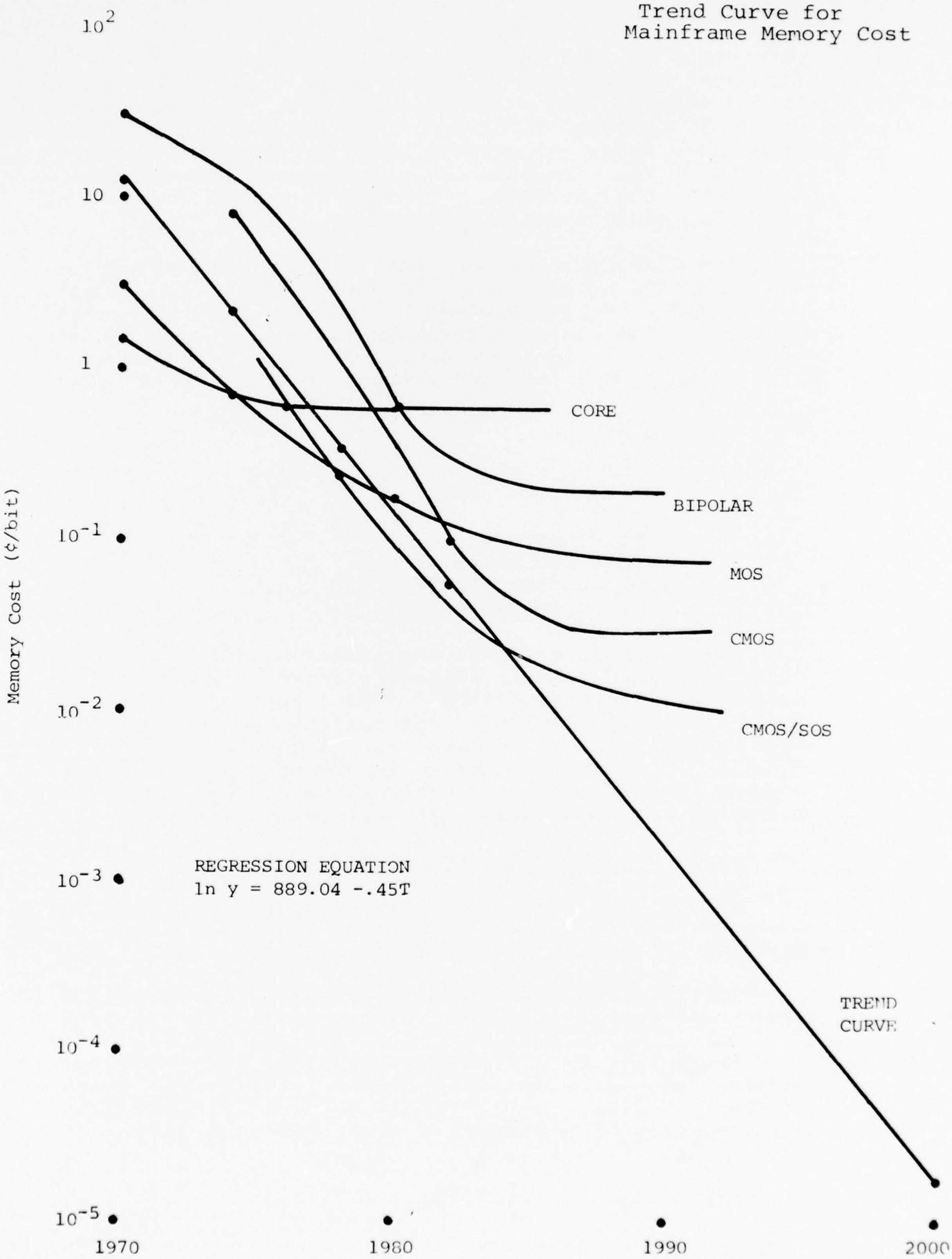


Figure A-21 shows cost/bit comparisons for the various memory devices. It should be remembered that the figures apply to devices with similar access times and memory capacity. The curves, therefore, represent medians of the range of values found for all systems, some having more exacting performance requirements. It can be seen, however, that MOS and core memory costs are now similar.

Bipolar memories cost more than either MOS or core and will probably not cost less than core prior to 1980. Bipolar memories do have a speed advantage as will be shown later.

The cost of CMOS technology is predicted to decrease rapidly. The growing commercial market for devices such as those used in electronic watches, calculators, and automobile electronics is producing a strong commercial R&D effort which will further reduce CMOS costs.

CMOS on sapphire substrates (CMOS/SOS) is another promising technology. The cost of sapphire substrate material is ten times that of ordinary CMOS, but SOS technology is expected to have a much higher manufacturing yield and density.

The projected cost decreases of solid-state memories by the year 2000 will certainly force the Army inventory of ADP equipment toward an all solid-state LSI memory configuration.

A.2.8.2.2 <u>Access and Cycle Time (ns)</u>

Figure A-22 shows switching speeds for the mainframe memory technologies. All present technologies are approaching fundamental limits. The projected access time of 1 ns (circa 2000 probably exceeds the capability required for future processors in automatic data processing applications.

Bipolar emitter-coupled logic (ECL) memories are already capable of 10 to 100 ns access times. Further great improvements in semiconductor performance are not expected. MOS speeds are expected to increase as the technology matures, with CMOS/SOS speeds increasing, which will challenge bipolar technology. Table A-11 summarizes present status in memory speeds.

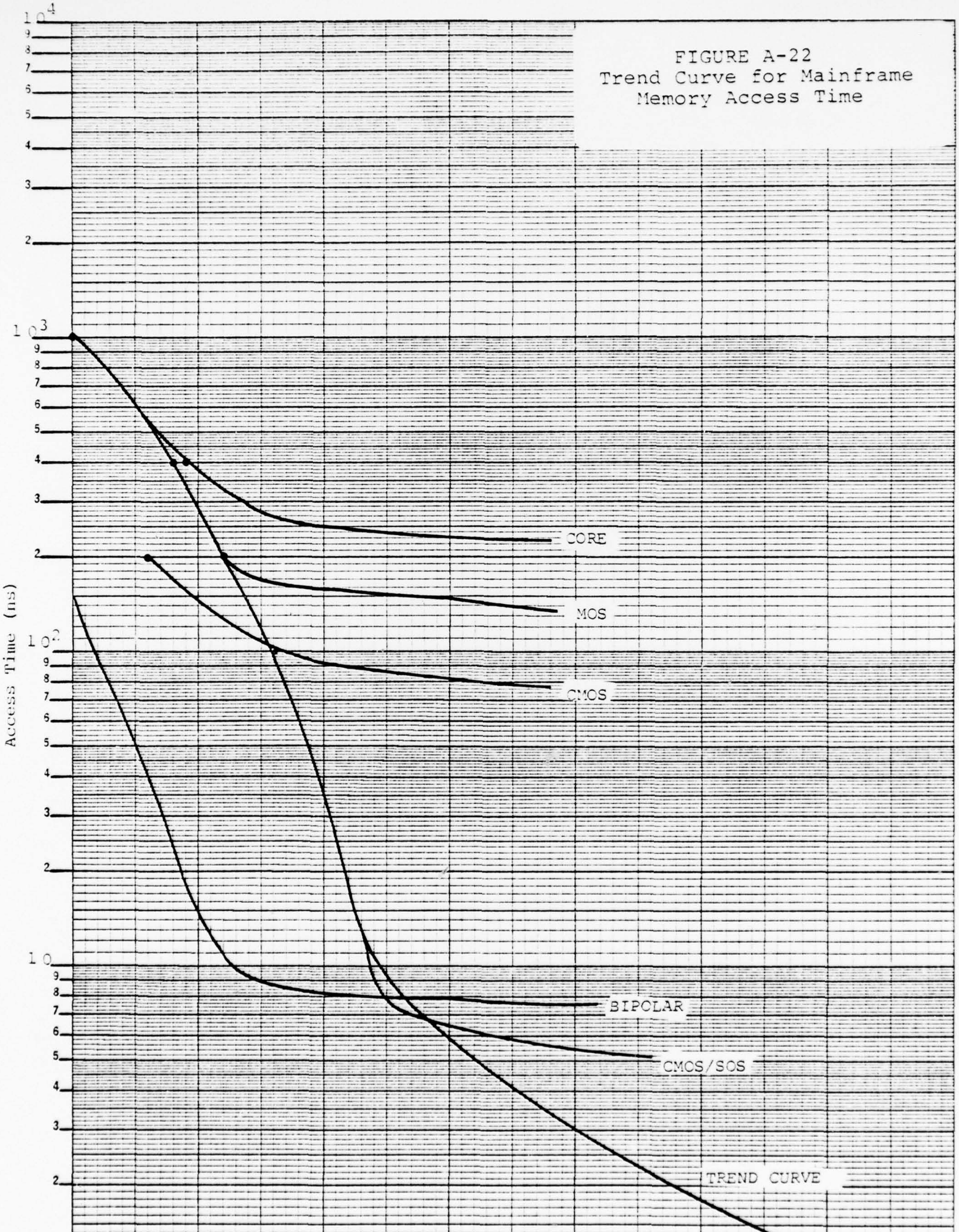


FIGURE A-22
Trend Curve for Mainframe Memory Access Time

TABLE A-11
Random Access Memory Speeds

Type	1976 Cycle Time (ns)
Magnetic Core	500
PMOS	400-500
NMOS	200-400
CMOS	100-200
Bipolar	10-20

A.2.8.2.3 Power Consumption (mW/bit)

Present power consumption of RAMs versus switching speed is shown in Figure A-23. Historically, this has decreased an order of magnitude every 3 or 4 years since 1966. Future trends in power consumption are shown in Figure A-24. This shows low-speed bipolar, PMOS, NMOS, and CMOS/SOS RAMs. Future technologies will permit a continued decrease in power consumption of an order of magnitude in 5 years or so.

4.2.8.2.4 Density (bits/in^2)

Figure A-25 shows the trends for storage densities of semiconductor RAMs. Currently, NMOS and PMOS are the densest; bipolar is about half as dense. CMOS/SOS density is expected to meet the others rapidly, though it is presently low.

LSI random-access memory density will reach 10^6 bits/in^2 by 1980 which may be a plateau. Present photomasking, etching, and diffusion processes will not support higher densities. Other developments (such as the use of electron beams and ion implementation) may permit even higher densities.

In contrast to the rapid increase in semiconductor memory density, core memory densities are not increasing and further improvements are not expected. Estimates of core storage density range from 1000 to 2500 bits/in^2.

FIGURE A-23
Speed - Power Curves for
Present Semiconductor RAMs

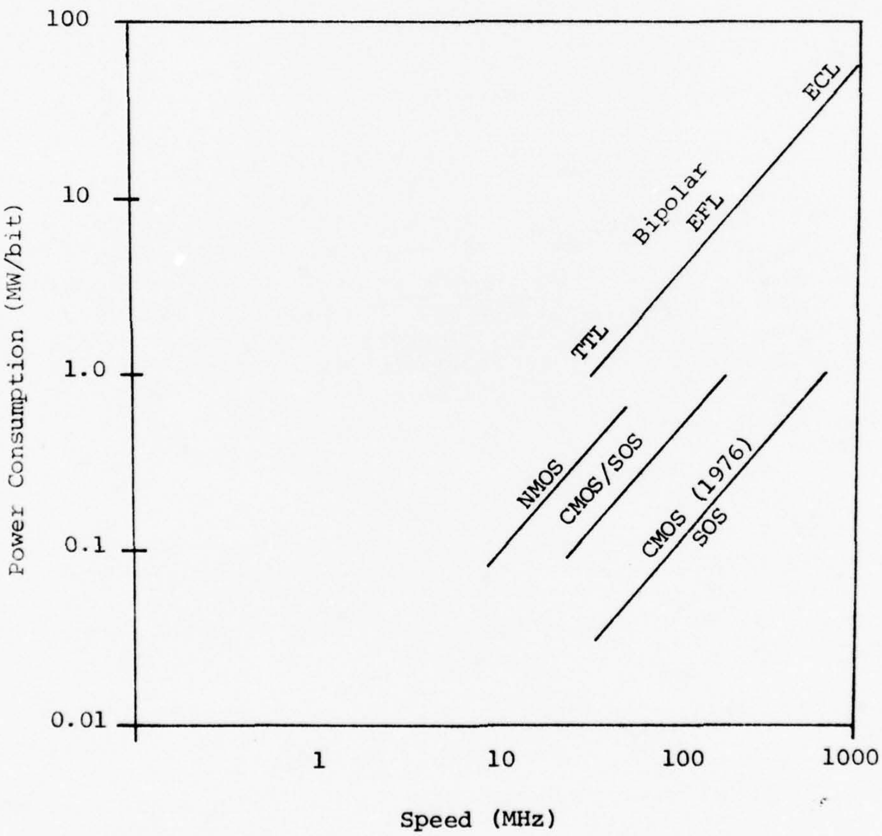
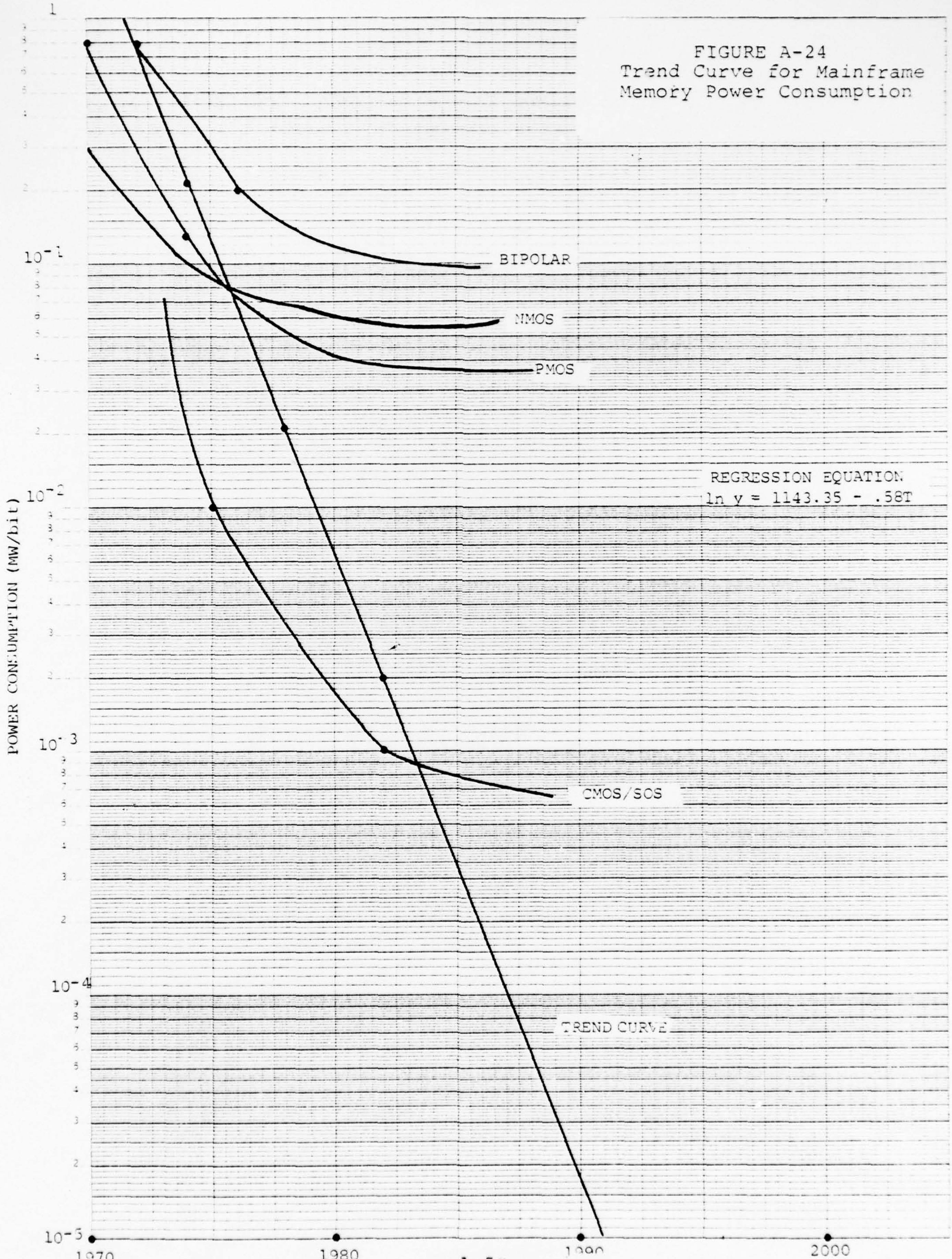


FIGURE A-24
Trend Curve for Mainframe Memory Power Consumption



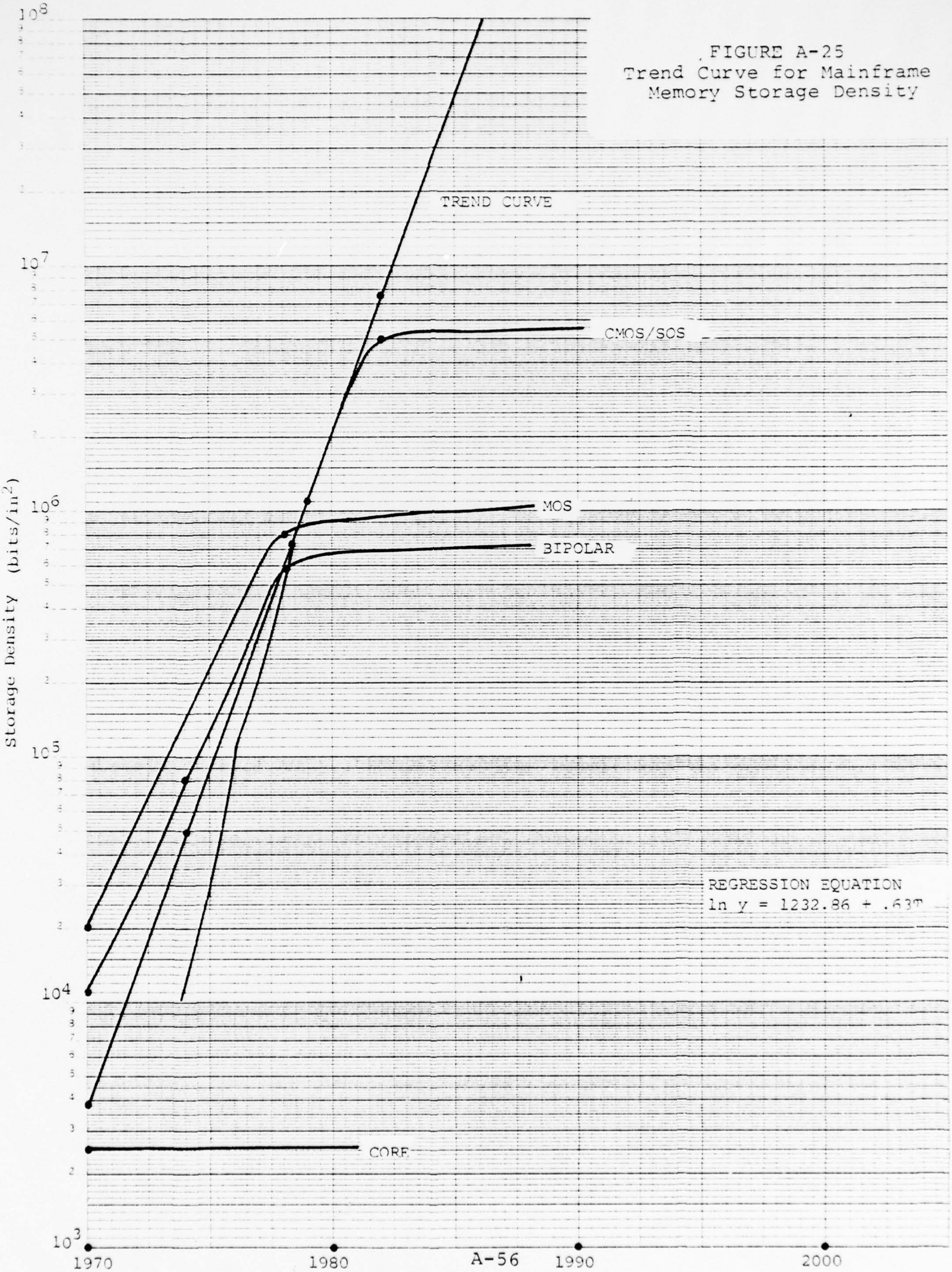


FIGURE A-25
Trend Curve for Mainframe Memory Storage Density
TREND CURVE
CMOS/SOS
MOS
BIPOLAR
CORE
REGRESSION EQUATION
ln y = 1232.86 + .63T
Storage Density (bits/in²)
10⁸
10⁷
10⁶
10⁵
10⁴
10³
1970
1980
1990
2000

A.2.9 Auxiliary Memories

A.2.9.1 General

Auxiliary memories provide specialized storage capabilities apart from computer mainframe memories. These include special-purpose, low-capacity memories such as shift registers and ROMs, as well as high-capacity memories to inexpensively store large amounts of data.

The special-purpose shift registers and ROMs are predominately solid-state devices. Shift registers are similar to RAMs, but because of their simpler circuitry, can be made denser, faster, cheaper, and less power consuming than RAMs. ROMs are used to store programs and frequently used routines. Using ROMs for this purpose provides faster access and lower power consumption than storing them in the mainframe memory. ROMs are particularly advantageous in mini- and microcomputer applications because of the shorter word lengths and limited mainframe memories involved.

High-capacity memory applications, also known as mass or bulk storage, are used for storing programs as adjuncts to processor mainframe memories or for preserving vast amounts of data that are to be retrieved in times on the order of hours, days, or a year later. The various types of mass storage systems are:

- Magnetic-tape storage units
- Rotating devices - magnetic drums and disks
- Extended magnetic core
- Electrio-optical
- Solid-state CCDs, magnetic bubbles, Josephson junction devices.

Magnetic tape, drums, and disks will continuously improve. Reduction of mechancial motion required will decrease the average access time. The high cost (1.5 cents per bit) of extended magnetic core relegates this technology to special-purpose uses where high speed is essential. Although these systems will exist for some time, new technologies promise revolutionary changes in mass storage systems.

These new technologies are optical storage, CCDs, and Josephson junction cells. Optical storage techniques involve writing with a light source on photographic material. Storage may be either in single bits or in holographic form if lasers are used for writing the information. An advantage to holographic storage is that if a portion of the photographic material is destroyed, the overall signal-to-noise ratio is reduced but no bits are completely lost. This technology promises large capacity, access time in microseconds, and low power consumption at reasonable cost. Similar in concept, an electron beam can record information on storage material such a semiconductor. The advantages of electron beam storage are similar to those of optical storage. Electron beam deflection technology is more advanced than optical storage because of years of experience gained with cathode ray tubes.

CCDs use MOS capacitor chains and are fabricated using standard LSI technology. These devices offer a potential for high information density since they employ passive storage devices requiring no external contacts. MOS capacitors can be fabricated entirely on the surface of the substrate allowing very high packing densities (presently approaching 10^6 bits/in^2).

A disadvantage of CCDs is that data must be refreshed periodically to maintain storage. Also, because of the serial nature of their construction, they cannot be used in random access applications. CCDs will find uses in serial memories putting them in direct competition with magnetic bubble devices.

Magnetic bubble devices are fabricated much the same as conventional ICS--using a thin film deposited on a substrate. This thin film, however, can be made to form or sustain magnetic domains shaped as fat, stubby cylinders known as bubbles. These bubbles are small, highly stable, densely packable, and movable at relatively high speed. They can be created, destroyed, and sensed by surface electrodes. A serial memory system using bubble technology can be fabricated with high packing density (presently 10^6 bits/in^2), low power consumption, and reasonable access time and cost.

As with CCDs, bubble memories cannot be used in random-access applications.

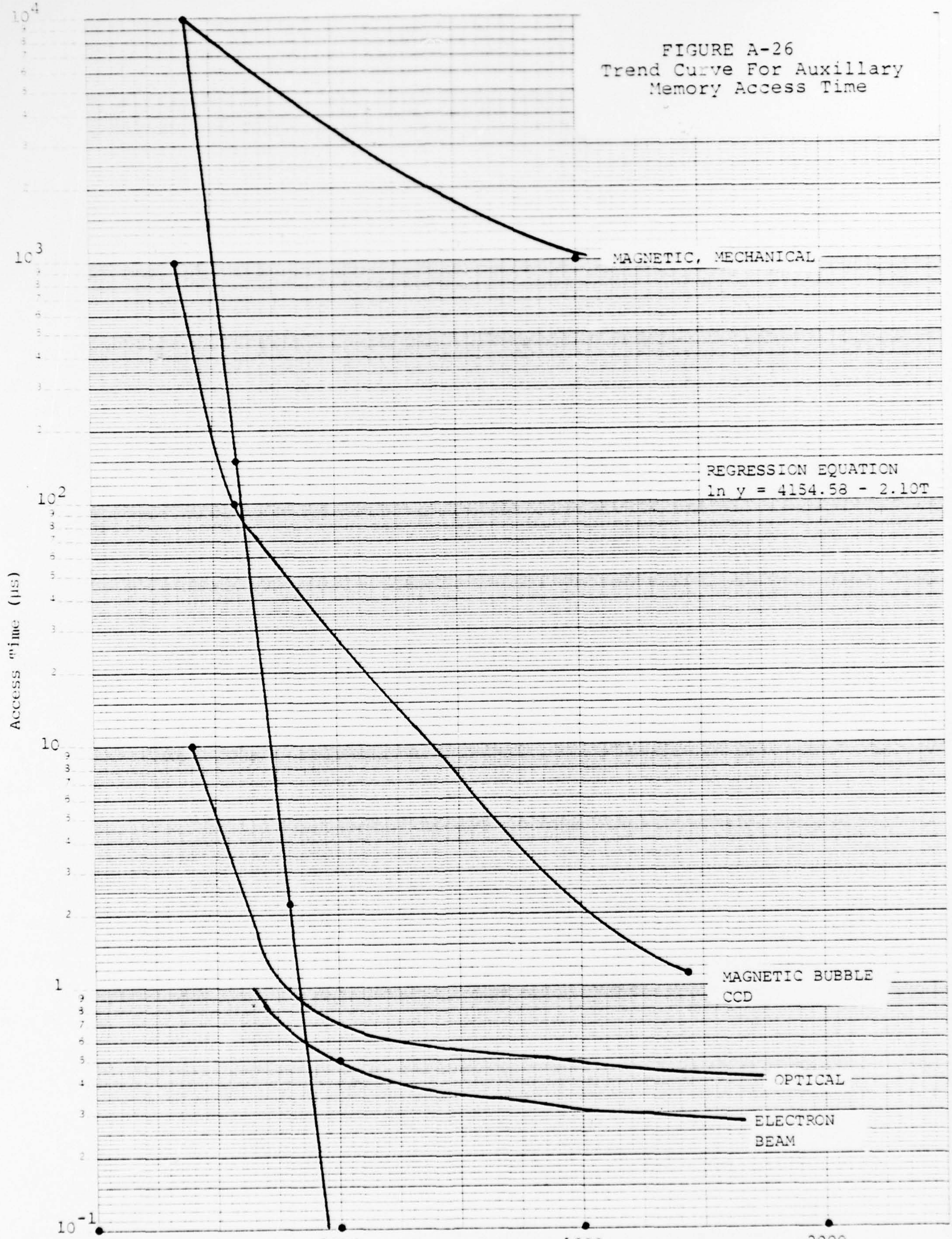


FIGURE A-26
Trend Curve For Auxillary
Memory Access Time
MAGNETIC, MECHANICAL
REGRESSION EQUATION
ln y = 4154.58 - 2.10T
MAGNETIC BUBBLE
CCD
OPTICAL
ELECTRON
BEAM
Access Time (μs)
10^4
10^3
10^2
10
1
10^{-1}
1970
1980
1990
2000

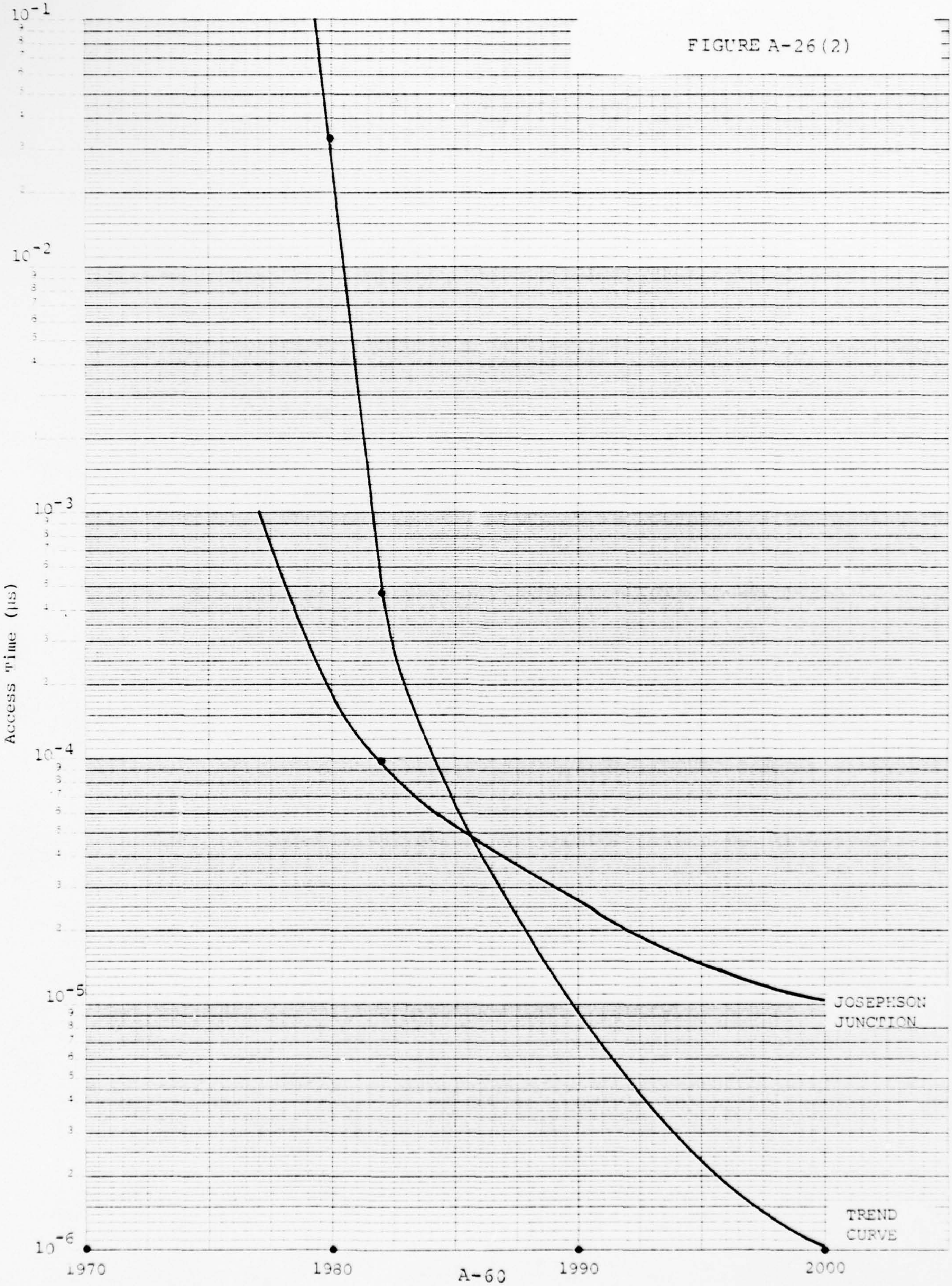


FIGURE A-26(2)
Access Time (μs)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
1970
1980
1990
2000
JOSEPHSON JUNCTION
TREND CURVE

A technology that is farther from practical application than any of those previously discussed, but which offers outstanding potential, is the Josephson junction device. This device employs a cryogenic superconducting junction that can store and sense minute magnetic fields. It has a very low power consumption and can switch at picosecond rates.

Auxiliary memory systems projections are shown in Figures A-26 through A-28. The parameters projected are access time (μs), memory cost (cents/bit), and storage density (bits/in^2). In addition, system capacities are presented in Table A-12. These parameters are discussed in the following paragraphs.

A.2.9.2 Access Time (μs)

The important trend in mass memory systems will be the emergence of systems with access times and costs midway between those of present mainframe and mass memories. (Access times between a μs and a ms and costs between 10^{-1} and 10^{-3} cents per bit.) CCDs, magnetic bubbles, electron beam, and optical memories will possibly fill this need in the next 10 years. Access time projections are shown in Figure A-26. If a projection limit for mainframe memories based on cost and requirements of 1 ns is appropriate, an access time limit for auxiliary memories based on the same considerations of 100-1000 ns would be logical. This requirement could be satisfied by optical and electron beam assessing techniques.

The projections illustrate the revolutionary improvements possible in future mass memory systems using Josephson junction devices. These memory systems are still in the basic research stage and although they exhibit outstanding characteristics, their capability for use in practical systems is yet unproven. Laboratory gates have achieved switching times of 10-100 picoseconds while dissipating 10^{-5} watts per gate. Josephson junction devices do not dissapate power when not switching, therefore, their power consumption is correspondingly less at low data rates. The achievable packing density of Josephson junction devices has been estimated at 10^4 to 10^5 bits/in^2.

A.2.9.3 Mass Memory Cost (Cents/Bit)

Future costs of mass memory sytems are expected follow two basic trends: (1) costs of magnetic tape, disk, and cassette can be expected to decrease; (2) slightly more expensive systems such as CCDs and magnetic bubbles will be used because of their much faster access times. Future holographic or electron beam memory systems will be a later development providing 1 μs access with capacity and cost competitive with magnetic disk. However, for applications requiring very large capacity at least cost, magnetic tape will continue to be used for many years. Figure A-27 shows mass memory cost trends.

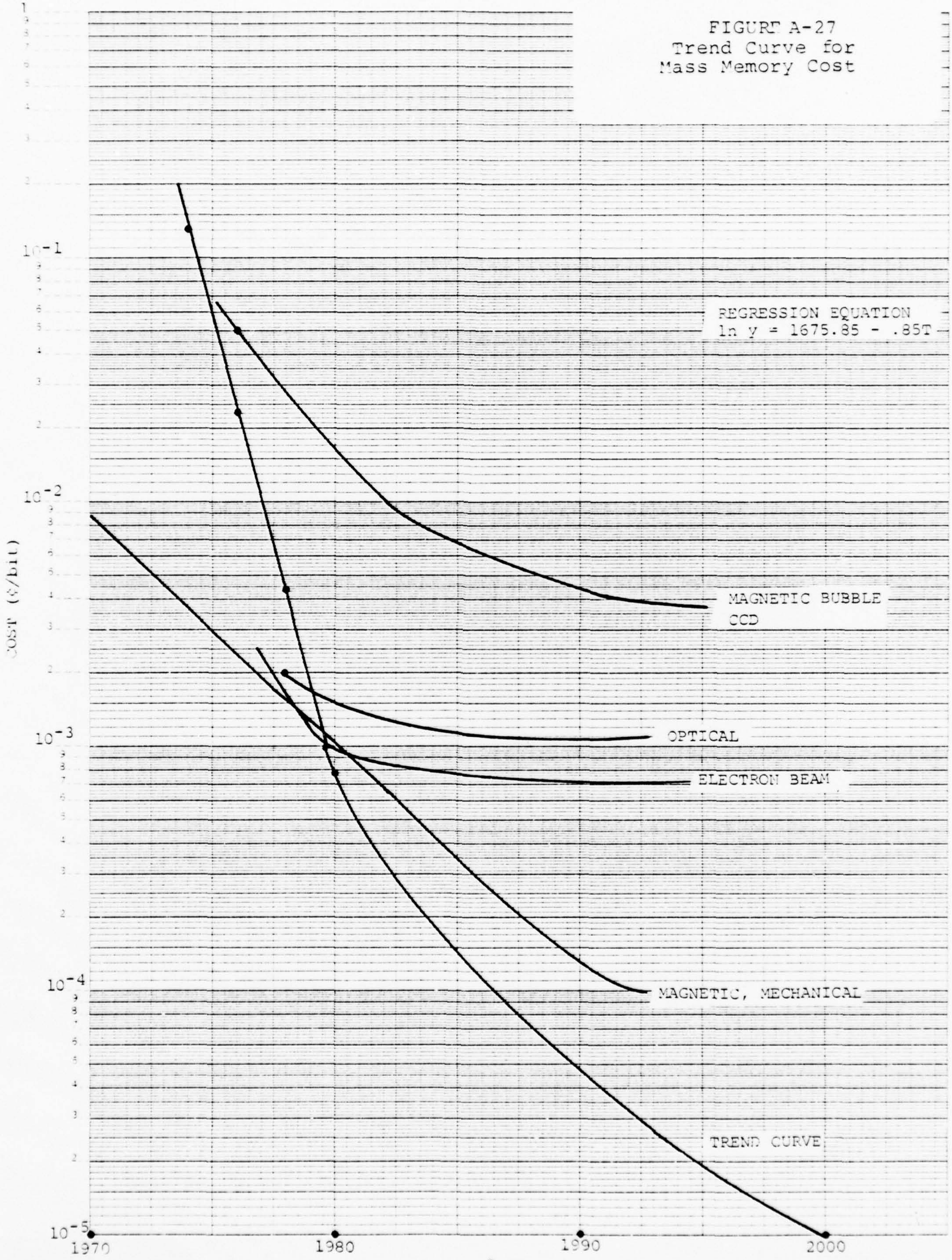
A.2.9.4 Mass Memory Capacity (Bits)

Typical capacities for mass memory technologies are listed in Table A-12. Capacity will be determined by system cost and performance considerations; however, in the future much higher performance (access time, cost, power consumption) will be available.

TABLE A-12
Mass Memory Capacity

Technology	Typical Capacity (Bits)	Status
Magnetic Tape	$10^{10} - 10^{12}$	Mature technology
Laser Punched Tape	10^{12}	Recently available
Magnetic Disk and Drum	$10^{6} - 10^{11}$	Mature technology
Magnetic Tape Cassette	$10^{6} - 10^{7}$	Mature technology New application
Magnetic Bubbles	$10^{6} - 10^{9}$	Under development, practical systems by 1975
Optical	$10^{8} - 10^{10}$	Under development, practical systems by 1978-80
Electron Beam	$10^{8} - 10^{10}$	Under development, practical systems by 1978-80

FIGURE A-27
Trend Curve for
Mass Memory Cost



A.2.9.5 Mass Memory Storage Density (bits/in^2)

Figure A-28 shows storage density trends for mass memory technologies. The storage densities of tape and disk systems will show continued increases, but newer technologies will achieve higher density. The electron beam system density shown is lower than the optical memory because the semiconductor grid used for recording limits the miniaturization achievable.

A.2.9.6 Mass Memory Transfer Data Rates (Bits/Sec)

The potential for increasing mass memory read/write rates is limited. Parallel operation of recording devices will afford higher data rates; however, transmission link limits would soon be encountered. Typical transfer data rates for various technologies are listed in Table A-13.

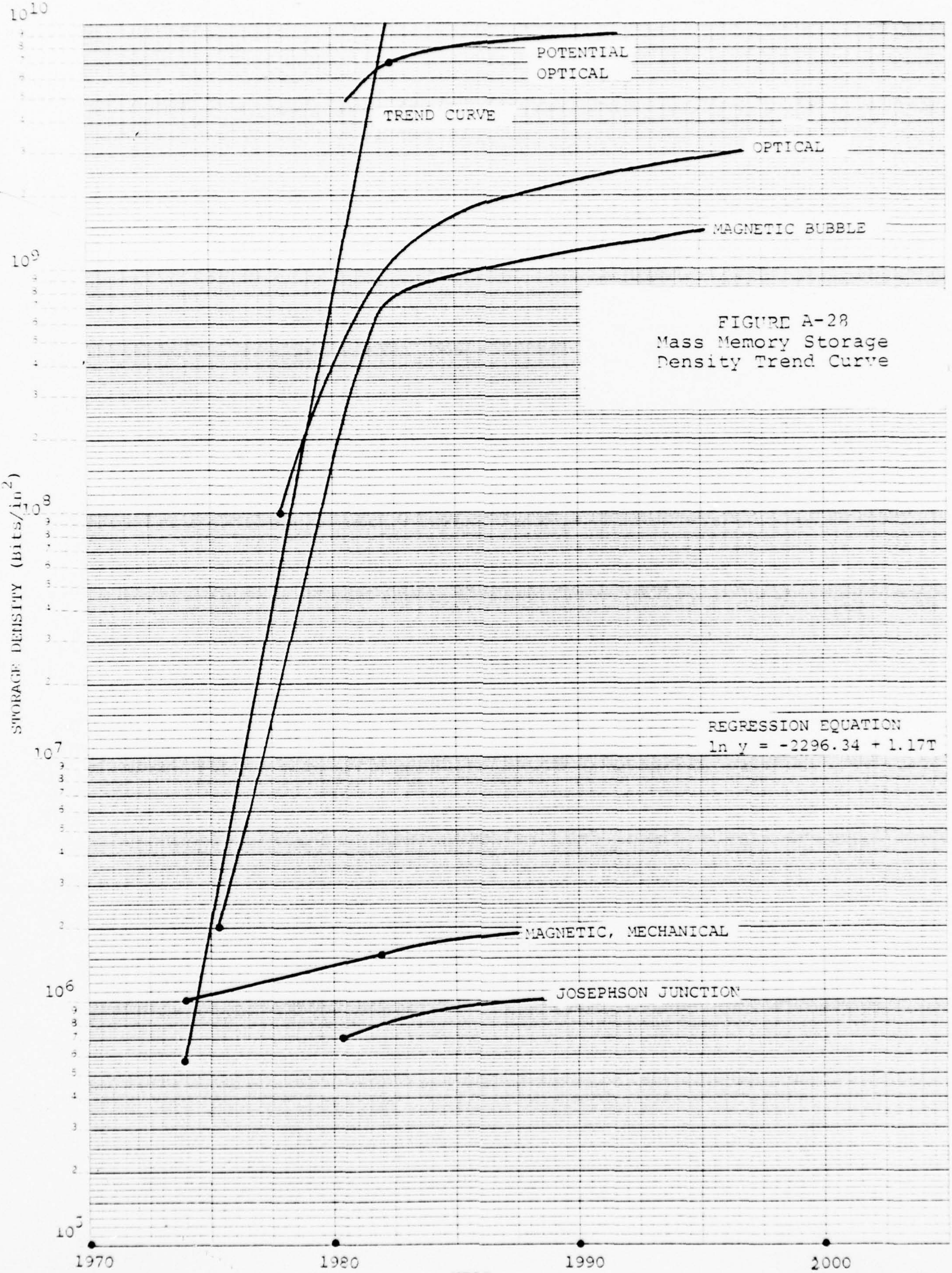
TABLE A-13
Typical Transfer Data Rates

Type	Data Rate (bits/sec)	Year Available
Electron Beam	$10^7 - 10^8$	1978
Holotape	$10^7 - 10^8$	1975-78
Magnetic Tape	10^7	1978
CCD	10^7	1975
Magnetic Disk	$10^6 - 10^7$	1978
Magnetic Bubble	$10^5 - 10^6$	1975
Magnetic Tape Cassette	10^4	1978

A.2.10 ADP Displays

Three generations of ADP displays are projected to the year 2000. The salient features of each generation for large- and small-scale tactical ADP systems are as follows:

- First generation - 1978 (small scale)
  - Plasma display
  - Graphic/alphanumeric capacity



POTENTIAL OPTICAL
TREND CURVE
OPTICAL
MAGNETIC BUBBLE
FIGURE A-28
Mass Memory Storage
Density Trend Curve
REGRESSION EQUATION
ln y = -2296.34 + 1.17T
MAGNETIC, MECHANICAL
JOSEPHSON JUNCTION
STORAGE DENSITY (Bits/in²)
YEAR
1970
1980
1990
2000

- Superimposed data possible
- 10" x 10" screen
- 1024 elements
- Operator-select write/erase while viewing
- Multicolor

. First generation - 1978 (large scale)

- Overlay reproduction equipment
- Produces map size transparency, in monocolor, with display data
- Dry Mylar base film
- Transparency displayed on large screen
- Polychromic technology to achieve multicolor

. Second generation - 1982

- Modular
- Multicolor
- Compatible with ICs
- 512 LEDs, each source 1½" x 3/4"
- Integrated decoding and driving circuitry
- Visible in high ambient light conditions

. Third generation - 1985

- Improved second generation module
- 4096 LEDs, each source 1½" x 3"
- One red and one green LED at each display point
- Display alphanumerics and graphics in a 4' by 4' area

. Post 1985 - monolithic displays.

Characteristics of both large- and small-scale displays will exhibit similar performance trends in the post-1985 time period.

The LEDs used in post-1985 systems will be off-the-shelf commercial units, configured in matrix arrays. These are addressed by a thin film transistor array in registration with the display panel light sources. Third generation displays will use two LEDs of different colors at each panel sight to provide a multicolor capability.

Second and third generation displays will be common in systems deployed during the 1985-2000 time frame.

Further information on displays is contained in Subsection A.2.1.

A.2.3.11 Surface Acoustic Wave Devices

A.2.11.1 General

Time-delay functions are often required for analog and digital signal processing. The relatively slow propagation of acoustic waves can be used to provide the necessary delay. Electrical energy is converted to acoustic energy transmitted through an acoustic medium, then reconverted to electrical energy. The acoustic wave propagation is four or five orders of magnitude slower than electrical waves depending on the acoustic medium. Until recently, acoustic-delay devices used a bulk medium resulting in a relatively large, expensive, and power-consuming device. Surface acoustic wave (SAW) devices are a new development which use the principle of SAW propagation in piezo-electric solids. They are smaller, use less power, and are cheaper than bulk-media devices. Thin-film techniques are used in the fabrication of SAW devices. Some devices applications are:

- Matched filters
- Spread-spectrum filters
- Pseudo-random noise synthesizer
- Frequency hopping.

SAW devices are unique acoustic-delay devices; the control logic in either bipolar or MOS implementation can be integrated in the same chip as the SAW structure. The characteristics of several presently available SAW devices are listed in Table A-14.

TABLE A-14
SAW Device Characteristics

Device	Insertion Loss	Center Frequency	Throughput Rate	Remarks
Switchable Matched Filter	20 dB	60 MHz	10 Mb/s	Bipolar logic
Matched Filter			10 Mb/s	Production cost estimated \$10 to \$40 MOS logic
Spread Spectrum		40,55,70, 85,100,115, 130 Mb/s		
Delay Line	18 dB	700 MHz	BW=24%	6μs delay

A.2.11.2 Forecast

Current research activities should lead to the deployment of the following SAW devices by the mid 1980s:

- Adaptive filters with a wide range in frequency, bandwidth, and insertion loss for implementation in the VHF-UHF frequency band
- Inexpensive, monolithic, narrowband, surface wave resonators for use as filters (both passband and stopband) and oscillators
- A wideband 500-MHz, 5-ms pulse compression filter for use with an electronic warfare microscan receiver
- Acoustic weighing filters to achieve high out-of-band rejection levels greater than 60 dB.

In the 1985-2000 time frame, SAW devices and CCDs will perform similar functions, although SAW devices will be operating at several hundred MHz while CCD devices will generally be operating below 5 MHz. It must be remembered however, that SAW devices are analog and CCDs are digital.

A.2.12 Switching

Electromechanical switching technology is being replaced by all-electronic systems. In commercial work, this change began with the Bell Telephone Electronic Switching System (ESS) concept. In the military community, the AN/TTC-39 development started the changeover to electronic switching.

Early electronic switches were designed for analog traffic and used space-division matrices. Newer developments will use time-division matrices for digital signals or both space and time division as in the AN/TTC-39 switch which is an analog/digital hybrid.

Future switching system performance will be increased predominately through improvements in LSI technology. The use of MOS will increase as greater operating speeds are attained with that technology. This will allow future systems to consume less power. LSI technologies were detailed in Subsection A.2.4.

The operating speed of current solid-state, time-division matrices is much faster than the time required by the processor to command the connection to be made. The cycle time of the central memory is the limiting factor in switching speed. CPUs using ECL gates with gate delays of 200 picoseconds will be available by 1985. In this type of system, memory cycle times on the order of 5 ns are forecast with a 1-ns cycle time predicted by the year 2000.

As processor speeds increase and LSI technology increases chip complexity while reducing cost, the processor capacity will far surpass the amount of traffic that can be economically handled at a single node. Network cost constraints will then be concern switching matrices and transmission facilities. The excess processing capacity can be harnessed bu dynamic intracall allocation of resources to optimize the use of these components. A system of this type could handle voice and data traffic concurrently.

A.2.13 Frequency Control Devices

Traditional frequency control methods using crystals will be improved. New processing methods for fabrication of precision quartz crystal resonators are being developed. The processes will include: ultraviolet/ozone cleaning; a nickel electrobonding process allowing nearly stress-free mounting of resonators; a laser-assisted X-ray orientation method for measuring angle of cut which eliminates significant tolerance errors; and new ceramic flat packs for crystal resonators with improved hermeticity. Details of specific crystal resonator development to be fielded in the early 1980s are as follows:

- Microcircuit, temperature-compensated, low-power crystal oscillator
  - VHF-FM radio reference frequency synthesizer application
  - Frequency tolerance: ±6 ppm/5 years
  - Frequency versus temperature stability: ±2.5 ppm over temperature range of -40° to 75° C
  - Frequency aging: ±2.5 ppm over 5 years
  - Other effects: frequency error ±1 ppm
  - Thick film microcircuit: 0.2 in^2
- High shock resistant, voltage-controlled crystal oscillator
  - Narrowband sensor transmitter application for use with REMBASS data transmission system
  - VCO range: 8 to 22 MHz
  - Frequency tolerance: ±5 ppm
  - Frequency stability over -40° to 75° C temperature range: ±2 ppm
  - One percent linearity 100 ppm frequency deviation performance
  - Withstand 15,000 G shock in expected impact direction
  - Piecewise linear curve-fitted diode function generator for temperature and linearity compensation

- High-stability, temperature-compensated crystal oscillator
  - Reference oscillator for TRCS radio sets
  - Frequency tolerance: ± 0.83 ppm
  - Digital temperature compensation using ROM programmed with higher order corrective function
  - 125 mW power consumption
  - Frequency aging: ± 0.2 ppm/year
  - 2 in^3 in size
  - ± 0.05 ppm frequency stability over -46 to $\overline{8}5$ C temperature range.

Research is continuing on fabrication techniques for crystals to be used in crystal resonators. This effort will produce frequency control circuits with better thermal stability, frequency stability, and resistance to shock and acceleration.

A new development using laser technology provides stability comparable to cesium standards. The salient performance characteristics of this development are as follows:

- Size: 20" x 40"
- Frequency stability: similar to cesium
- Principle of operation: CO_2 standing wave saturation absorption resonance
- Source: CO_2 laser
- Frequency multipler: 5 to 30 MHz
- Application: highly portable, precise time reference
- Availability: approximately 1985.

APPENDIX B

REGRESSION ANALYSIS

APPENDIX B

REGRESSION ANALYSIS

Regression analysis determines the "best fit" equation to a set of ordered pairs of values. In the analyses conducted in this study, simple regression techniques were used (the relations between only two variables were considered). The form of the equation governing the relationship between the two variables was assumed to be an exponential function of the form $Y = ae^{bx}$. By taking logarithms of both sides of the equation, the equation is converted to a linear equation of the form $\ln Y = \ln a + bx$.

Figure B-1 shows a linear equation plotted together with the set of data points upon which the equation is based. The u_i shown is the error term, i.e., the difference between the observed value Y_i and and the computed value of Y_i. This relationship can be expressed as follows:

$$\ln Y_i = \ln a + bx_i + u_i$$

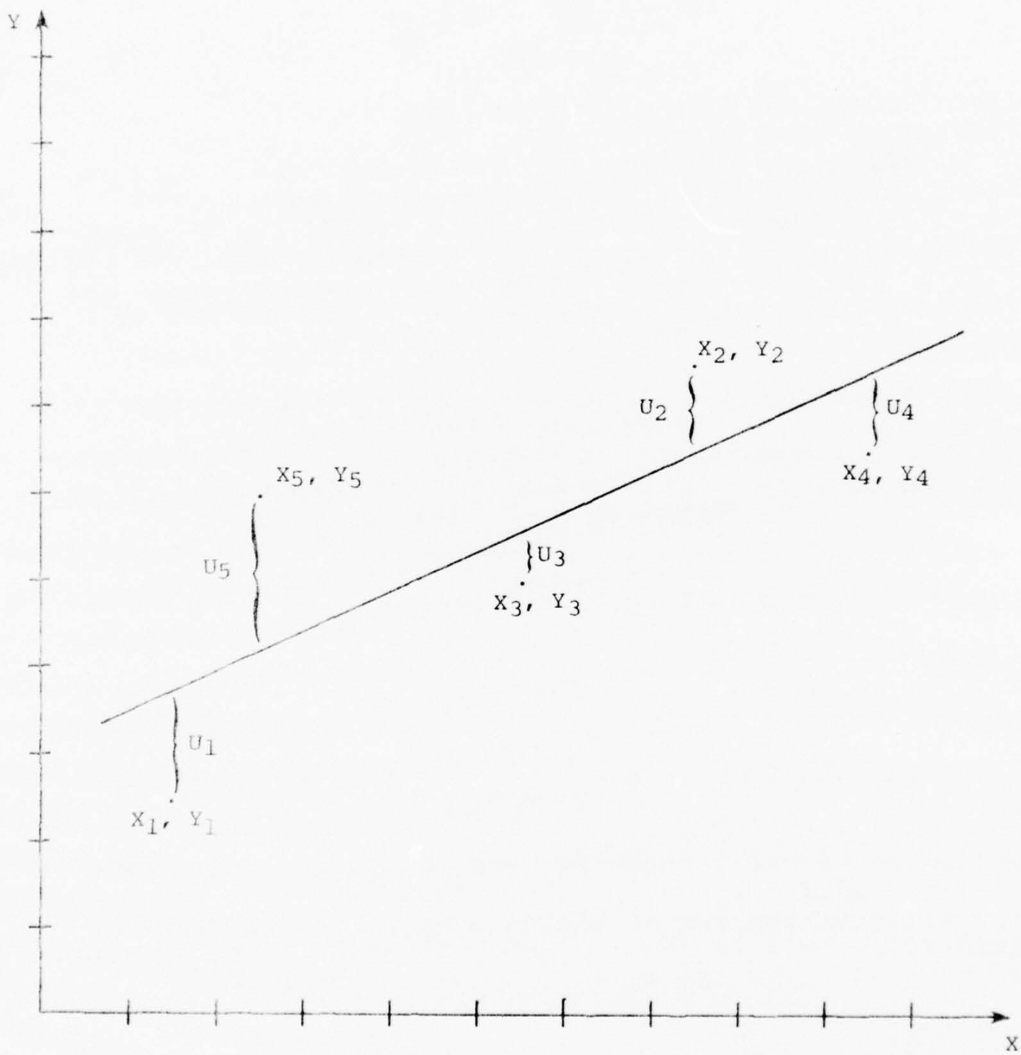
Solving for the error term u_i,

$$u_i = \ln Y_i - \ln a - bx_i$$

To obtain the best fit equation, the resulting error terms must be minimized. It can be shown that the error terms are minimized if the sum of the squares of the error terms is minimized. This is known as the method of least squares. The expression to be minimized is:

$$\sum_{i=1}^{n} u_i^2 = \sum_{i=1}^{n} (\ln Y_i - \ln a - bx_i)^2$$

FIGURE B-1
Example of Curve Fitting
Using Regression Analysis



To minimize this equation, it is necessary to differentiate the above equation with respect to a and b, set the partial derivatives equal to zero, and solve the resulting two equation systems for a and b:

$$\frac{\partial \sum_{i=1}^{n} u_i^{\,2}}{\partial a} = -2 \sum_{i=1}^{n} (\ln Y_i - a - bx_i) = 0$$

$$\frac{\partial \sum_{i=1}^{n} u_i^{\,2}}{\partial b} = -2 \sum_{i=1}^{n} x_i \, (Y_i - a - b \ln x_i) = 0$$

Solving for a and b yields the following equations

$$b = \frac{\sum_{i=1}^{n} (x_i - x) \, (\ln Y_i - \overline{\ln Y})}{\sum_{i=1}^{n} (x_i - x)^2}$$

$$a = \overline{\ln Y} - bx$$

where $\overline{\ln Y}$ and X represent the average value of the natural logarithm of the Y and X data point values, respectively.

This discussion shows the theoretical basis of the regression analyses performed in this study. In practice, the data points were plotted on semi-log paper which effectively takes the logarithm of both sides of the equation. Also, the calculations were actually performed on an HP-25 calculator programmed to perform regression analysis.

APPENDIX C

INTERVIEWS FOR ARMY METROLOGY REQUIREMENTS

APPENDIX C

INTERVIEWS FOR ARMY METROLOGY REQUIREMENTS

C.1. APPROACH

Following the technology forecasting effort based on a search of available literature, individuals within ECOM Laboratories having specific knowledge of one or more of the technical areas being considered were interviewed. These interviews were conducted to verify the projections which were based on available literature; when projections did not agree with the interviewees' experience or expectations, new data points were obtained.

Potential interviewees were selected by Booz, Allen and the ECOM point of contact. After initially contacting each potential interviewee by telephone, a meeting time was arranged. Each interviewee was sent a copy of the handout shown in Exhibit C-1 prior to the interview. In this manner, the interviewee could become familiar with the topics to be discussed and the problems being addressed, and could gather any information that might be required.

In almost all instances the respondents were not prepared to provide data in the detail requested; consequently, the responses obtained were generally of a philosophical nature and are briefly summarized in the following subsections.

C.2. INDIVIDUAL INTERVIEWS

The following summaries present the viewpoints offered by the indicated respondents. The comments are pertinent to development programs that are current or planned within the technical area of the particular expert.

The presentation is organized by laboratory and then subdivided by technical area.

EXHIBIT C-1

TECHNOLOGY FORECAST INTERVIEW QUESTIONNAIRE

1. STATEMENT OF THE PROBLEM

A requirement exists for the contractor (Booz, Allen & Hamilton) to provide the Government (U.S. Army Electronics Command) with a study relating to the test, evaluation, and key parameter measurement requirements of future generations of electronic equipment and systems in the general application areas of:

- Communications
- Avionics
- Target detection and acquisition
- Electronic warfare.

A critical part of this study will be projection, to the year 2000, of the functional capability or technical performance parameters that best describe the level of achievement attained in the more critical technology areas.

2. GENERAL COMMENTS

You have been selected as an interviewee in the technology forecasting part of this effort because of your knowledge of technological areas relevant to the study. These technological areas are detailed in Attachment 1. Since this study is concerned with projecting the capabilities require of test equipment to service and maintain future Army communications-electronics (C-E) equipment, the technological areas of interest are those which are related to metrology. Of prime interest are technological advances which will have an impact on the capability of test equipment to quickly and accurately determine equipment status.

Because of the time frame being considered in this study (1985-2000), it will be virtually impossible to determine the specific technology that will be used in future equipment. However, historical evidence supports the postulate that an underlying trend exists in any technology area and that this trend will end in one of two ways:

- It will encounter a natural physical barrier, such as the speed of light.
- It will be totally overtaken by another technology area, such as the advent of the steamship and the demise of sail as the propulsion means for commercial vessels.

A second postulate is that, superimposed on this basic trend curve is a family of technologies that fall into three categories:

- Historical approaches that are now obsolete.
- Current and overtaking approaches that are well known and of immediate interest.
- Future approaches that are now unknown but whose emergence is assured by the postulated trend.

The answers to the questions you are being asked to consider will provide the Booz, Allen study team with the information necessary to make the desired technology forecasts.

3. QUESTIONS

(1) Question 1

Identify from Attachment 1 the critical technology areas with which you are familiar and which will be significant to C-E equipment throughout the period 1985-2000. If you are familiar with additional technological areas that should be included, they can be added; however, these technology areas should relate to parameter or performance measurement requirements needed to maintain electronic equipment, systems, and subsystems.

(2) Question 2

Identify any physical or practical limits, upper or lower, which would inhibit future evolutionary growth of the technology areas identified under Question 1.

(3) Question 3

Identify a maximum of five technical approaches or technologies (historic or current and overtaking) which characterize the technology areas under Question 1.

(4) Question 4

Identify the order of magnitude improvement from 1970 to 2000 for each technology area identified in Question 1 and each technical approach identified in Question 3. A statement of actual technical performance parameter values is preferred; a statement of order of magnitude advancement is acceptable.

(5) Question 5

If specific technical performance parameters can be given (ref. Question 4), identify a maximum of four metrology-related key technical performance parameters that should be projected.

(6) Question 6

For each technical performance parameter identified in Question 5, indicate when specific technologies move from development to production, i.e., at DT/OT II. For overtaking technologies, indicate the probability of moving from development to production by the indicated year. Please provide estimates of the technical performance parameter value at this point in the case of overtaking technologies. These estimates may also be required for current technologies.

(7) Question 7

Identify any additional data points on the performance curves of any of the technical approaches described in Question 6 which might be added to enhance understanding. Identify any significant comment that should be added as explanatory text.

NOTE: Respondents are requested not to provide documentary material in lieu of the interviews. It can be assumed that the pertinent documentary material is in the hands of the contractor, has been analyzed, and will be included elsewhere in the study.

	Technology Area	Achievement Level/ Performance Parameter
12.	ADP Displays	Functional Capability
13.	Surface Acoustics Wave Devices	Functional Capability
14.	Switching	Functional Capability
15.	Frequency Control Devices	Functional Capability
16.	Microelectronic Packaging	Functional Capability
17.	Batteries	(1) Energy Density (2) Storage Life (3) Temperature (4) Specific Cost
18.	Fuel Cells	Functional Capability
19.	Thermoelectronic Generators	Functional Capability

C.2.1 Communications/Automatic Data Processing Laboratory - Center for Communications Sciences (CENCOMS)

C.2.1.1 Signal Processing

Respondent: Mr. B. Goldberg

Comments:

- The technology areas that are of primary interest to the respondent are:
  - Digital voice coding
  - Tactical multiplex systems
  - Surface acoustic wave (SAW) devices
  - Channel characterization and simulation
  - Packetized communications
  - Source and error control coding
  - TDMA technology
  - Low probability of intercept (LPI) communications
  - Statistical communications
  - Modulation concepts
  - Facsimile
  - Optical character readers (OCR)
  - Record communications
  - Impulse noise modeling
  - Rate distortion theory
  - Time spread communications
  - Signal intercept threshold technology.
- Wholesale speech encoding of voice traffic over trunk networks will increase circuit traffic capacity by a factor of ten.
- Employment of new coding algorithms will reduce the channel bit rates from existing 16/32 kb/s to a new lower limit of 2.4 kb/s. Use of linear predictive encoding techniques may further reduce the channel bit rate to 1.7 kb/s. Channel rates of 2.4 kb/s should be achievable within 5 to 10 years.
- Rate distortion theory will be used to determine the minimum bit rate required to achieve acceptable fidelity.

- Packet radio communications will permit rapid circulation of information between nets. Traffic generated in a random fashion by one user will be available to all subscribers. Empty time slots will be detected and seized by users encountering busy conditions on first-try connections. The service will offer a greater information throughput capability, will be secure, provide antijam protection, and will not be vulnerable to intercept. The protocols associated with military operations may have to be altered in that field commanders will not have to go through various echelons to receive operational data. They will immediately receive such information as it is produced. Feasibility tests of the system will be performed in the 1978-79 time frame; engineering development models should be available by 1983; the system should be in the field by 2000.

- Programmable, spread-spectrum control devices will be achieved through the exploitation of charge-coupled devices (CCD) and SAW technology.

- Future test equipment will be required to recognize and identify the packets discussed above. Testing will be done on a "system attributes" basis with measurements accomplished with a random, sampled approach rather than being continuously measured as is currently done. Measurement times will be limited to a few hundred ns. Development of future test equipment concepts will be aided by the use of channel simulation models that will duplicate such communication channel characteristics as time and frequency dispersion of the transmitted signals.

- Test equipment will be developed in conjuction with new error-control coding techniques that will permit measurement of burst and random errors as they occur in the actual traffic-carrying channels. Test equipment memory will contain these actual error rate distributions for injection as stimuli into the system under test. This will overcome the current limitations of back-to-back testing.

- Smart terminals, controlled by microprocessors, will replace the current family of FATT(s). These terminals will contain a composition, editing, high-speed receiving, transmitting, and limited message storage capability.

- The EQUATE test system being used for maintenance of the AN/TTC-39 switch will be modified to accommodate the digital group multiplexer (DGM) family.

- New facsimile equipment will be developed using coding techniques that will reduce the channel bit rate by a factor of ten to one. Source encoding techniques will employ spectrum transform functions at optical wavelengths.

- Optical character reader (OCR) technology will have advanced by three orders of magnitude by the year 2000. Typewriter-prepared tests on DD Form 173 will be processed for transmission over digital circuits in JANAP 128 format without human intervention. The OCR(s) of the future will be microprocessor controlled, will be ultra reliable, and will have a multifont capability.

- Baseband conversion techniques using appropriate transfer functions will fit wideband data signals into existing channel spectrum allocations. Thus, source processing of information content and signal structure will permit baseband and spectrum compression ahead of the modulator stage so that existing channels can carry the traffic without increasing the channel frequency allocation.

C.2.1.2 Multichannel Transmission

Respondents: Mr. Kullback, Dr. Christian

Comments:

- The technology areas that are of primary interest to the respondents are:

  - UHF transmission
  - Optical transmission
  - Millimeter wave transmission
  - Microwave transmission
  - Fiber optics, cable, field wire.

- For UHF and microwave transmission, the transition from analog to digital traffic systems will have been completed by the year 2000.

- Error-correction techniques, such as bit interleaving to minimize burst errors and advanced modulation/detection techniques, will provide the dynamic troposcatter systems with a comparable quality of transmission as the more static line-of-sight systems. Bit rates of 5 Mb/s will be common for tactical applications; for strategic systems, rates of 25 Mb/s will be employed for LOS systems and up to 13 Mb/s for troposcatter systems.

- Companion test systems will be capable of measuring, in real time, over operational circuits, such performance parameters as signal-to-noise ratios, bit error rates, receiver noise figure, receiver sensitivity, transmitter power output, etc. In addition, future generations of automatic test equipment, circa 2000, will be capable of indicating trends or tendencies toward future failures. All major radio subsystems (i.e., IF amplifiers, modulators, etc.) will be amenable to functional testing and monitoring on a continuous, sampled, or snapshot basis. Multiple test points will be available on the test articles to accommodate trend measurements, analysis, and fault diagnosis.

- Through the use of higher bit rates, sophisticated coding schemes, etc., optimum spectrum occupancy will have been achieved both in a laboratory environment and on operational links.

- By 1985, automatic test equipment will be available for ensuring complete compliance with FCC regulations. Test systems will be capable of spectral analysis to automatically verify location of the 99% power points as opposed to the manual point-by-point techniques presently employed.

- By the year 2000, tactical radio systems will enjoy a substantial antijam protection capability. Equipment operators will be automatically advised when their transmission is subject to jamming, the nature of the interfering signals, and the countermeasures to be employed.

- In the area of millimeter wave transmission, it will be possible to measure bit error rates over atmospheric path lengths of up to 10 km. Test equipment will indicate channel availabilities and radiation/propagation conditions, and will provide a positive, visual notification of proper system operation. Millimeter wave transmission systems will enjoy extensive antijam protection by the year 2000.

- By the year 2000, radio transmission terminals will be capable of very rapid siting and will have been secured on an end-to-end basis.

- By the year 2000, automatic test equipment will be capable of rapid testing over the entire frequency spectrum up to 90 GHz. By 1985, this upper limit will be in the neighborhood of 65 GHz.

- By the year 2000, fiber optics transmission systems will largely have replaced coaxial cable systems in short-haul distribution systems. The closed nature of the fiber optics cable offers interference-free service, minimizes susceptibility to jamming and intercept, and provides high protection against the effects of EMP. These facilities provide high channel capacity and wide channel bandwidths. By 1985, the problems of uniform fiber consistency and fiber breakage will have been solved. Data rates of 25 Mb/s, the maximum foreseen for tactical applications, will be accommodated on fiber optics systems by 1982-83.

- By 1990, local distribution fiber optics transmission systems will have replaced 26-pair cable.

- By 1990, automatic test equipment will be available at the higher level maintenance echelons to perform component testing of fiber optics systems, to include the transmission medium as well as the sources and detectors.

- By 2000, single-mode optical fibers, operating at over 1 Gb/s, will be employed in some field installations. These systems will be characterized by rugged construction, laser driving sources and silicon avalanche detectors, and highly efficient coupling between the fiber and terminal devices.

- Present problems relating to the splicing and repeating capability of fiber optics transmission media will have been solved by 1990. Repeaters will be battery operated, obviating the necessity for metal power conductors in the fiber optics cable assemblies.

- The theoretical coupling loss limit between a multimode source and a single-mode fiber has been established at approximately 30 dB.

C.2.1.3 Net Radio

Respondent: Mr. I. Dodd

Comments:

- The net radio inventory within the Army is characterized by large quantities of equipment that, for economic reasons, requires a rather long period of operational life. These radios, once introduced, are seldom replaced in their entirety, but are subjected to periodic product improvements. Radios introduced in 1985 will still be in the field by the year 2000.

- The trend in manpack radios will be towards reduced size and weight with an attendent increase in sophistication.

- The historic trend in net radios has been from the vacuuum tube to the transistor and, finally, the discrete component configurations giving way to ICs.

- The VHF-FM SINCGARS family will be the standard net radio in the year 2000.

- Although it would be desirable to have radios of little weight and no power consumption, the radiative nature of a radio requires a certain minimum power consumption. Thus, the goal is to maximize the power conversion efficiency in order that the power input will match the power output requirements.

- Future generations of net radios, circa 2000, will employ solid-state, CMOS, IC, digital logic circuitry.

- The development of more efficient, tuned frequency control devices is an important objective. These devices will become more accurate, capable of faster tuning, and future frequency synthesizers will require less time and effort on the part of the operator. Fast frequency hopping will be employed as an ECCM measure in future net radios. The frequency hopping rate will be adjustable in accordance with the threat and such systems will tend to be highly complex.

- Component density and power consumption will be major limiting factors for future generations of net radios. Front control panels, such as in the AN/PRC-77, are becoming increasingly crowded. Further reductions in the size of these panels would be impractical if human operators are to have easy access to the control knobs and switches.

- Another major problem area that will surface as net radios become more complex and sophisticated will be the availability of trained manpower to service this equipment. Thus, operation of future generations of net radios must be made as foolproof as possible. Future net radios will be highly automatic, ultrareliable, and will incorporate novel self-healing features.

- The parameters that future automatic test equipment will have to measure are not likely to change, i.e., power output, noise, error rates, receiver sensitivity, etc. The fundamental characteristics of the net radios are not expected to undergo significant changes in the next 25 years. There will be some increase in logic to accommodate improved tuning capabilities as operating channels will be electronically selected. Some increase in memory will also be required. Signaling will be digitized and the radio's logic circuitry will be required to interpret these digital signals. Selection of channel separation will be accommodated by changing filter circuits.

- The AN/URC-78 will accommodate different channel separations without changing filters.

- Future net radios will have the capability for both slow and fast frequency hopping. Frequency hopping rates will extend from 100 hops/sec to hopping rates that exceed the channel bit rate, i.e., 16 kb/s.

- SINCGARS radios, i.e., AN/URC-78, are intended to serve as a baseline system and would not be fielded as such. Thus, the AN/URC-78 is more properly considered as a test bed or compilation of advanced concepts which is to be further refined before actually being produced and fielded.

- The AN/PRC-77 employes all solid-state technology. Older sets that utilize discrete components, such as the AN/VRC-12, will be modernized through a product improvement program in which vacuum tube circuitry will be replaced with newer devices.

- Future improvements in radio transmitters are limited by the broadband noise floor.

- The AN/PRC-70, a radio set that combines a number of operational modes, uses some IC(s) but does not employ LSI technology.

- Future net radios will have the capability for automatic antenna matching and will require associated sensing and logic circuitry.

- Laboratory tests on radio reliability often do not provide data that is consistent with field tests, i.e., 1500 hours MTBF obtained in a laboratory environment versus 52 hours MTBF observed in field tests of the same radios.

- Future generations of net radios will be equipped with a COMSEC capability.

- VHF radios will enjoy some increase in frequency bandwidth, i.e., 30 to 88 MHz, to accommodate a few more channels.

- The only future requirement for HF radios appears to be in map of the earth (NOE) aircraft communications applications. Long-range radio communications of the future will be achieved using satellite facilities. Special Forces may also continue to use HF radios.

- All-digital net radios will be in the field by the year 2000. These radios are not in exploratory development. However, the digital radio will not have the large dynamic ranges that can be effectivley handled by analog radios. Thus, by 1985, radios will not be all-digital but will employ more digital circuitry, such as in the frequency synthesizers. The basic VF and IF stages will remain analog.

- The advent of all-digital manpack radios would impose different test requirements.

C.2.1.4 Communications Sciences

Respondent: Mr. R. Riehs

Comments:

- The cost of current inventories of such large quantities of equipment as the manpack VHF radios and handheld gear will be the principal factor mitigating against rapid replacement of these systems in the future. This inventory of 250,000 items with the large, existing logistic tail is an overridding consideration in the determination of the optimum time for introducing new technologies. This equipment cannot simply be thrown away. Thus, systems like the new SINCGARS radio family will remain in the inventory for many years.

- The major obstacle to future size reductions in equipments made possible by the advent of LSI technology is the requirement for human operators to access the control knobs on equipment front panels. Thus, although equipment depths may approach zero, a minimum front panel dimension must be maintained.

- There may be no need for individual pieces of test equipment in the field by the year 2000. Testing will be largely accomplished by BITE, organic to the fielded assemblages.

- Future test equipment, at the higher echelons of maintenance, will incorporate microprocessors and will be fully programmable. BITE, incorporated in communications-electronic (C-E) equipment, will give an indication of potential failure conditions and will inform the operator when a particular module needs replacement. This capability should be available by the year 2000.

- The shortage of trained personnel to operate and maintain the future generations of C-E equipment will be a serious limitation. It will not be economically feasible to staff the number of field maintenance vans that would be required.

- Future generations of C-E equipment must be capable of self-checking and automatically switching in redundant components or circuitry when failure information on a peripheral teletype will be provided the operator. This information will include instructions to the operator as to what actions he must take. All the operator will be required to do is push the indicated buttons in response to the printout.

- C-E equipment will become increasingly sophisticated in the future and the human interface will pose a serious problem. The quality of future operators must be improved.

- The threat of electronic warfare will continue to grow. The basic intelligence threat must somehow be countered. Future C-E systems must be designed to be interference-proof. This requirement will further add to the complexity, cost, and size of the equipment. By 2000, techniques will be available to prevent the enemy from detecting the presence of an active electromagnetic emitter, thus ensuring a low probability of intercept. In the absence of an intercept capability, the enemy will not know where to direct his jammers.

- Spread-spectrum techniques will be widely employed by 1990 to reduce vulnerability to hostile threats. Psuedo-random coding will be utilized to make successful intercept even more difficult. These techniques consume bandwidth and reduce channel availability. By reducing the enemy's intercept capability, the antijam requirements are correspondingly reduced. Eventually, the costs of such systems produce an impenetrable barrier.

- Homing missiles will be developed by 1990 that can seek out and destroy enemy ECM devices.

- Another barrier problem is the self-jamming that may occur with the proliferation of C-E systems.

- As in the past, communications will continue to enjoy a lower priority when compared with aircraft, missiles, and other weapons systems. For example, integrated weapons systems, such as tanks, find difficulty in exchanging an increased communications capability for reduced fire power.

- The future of communications will show an increasing reliance on record traffic at the expense of voice traffic. The use of voice communications is inherently expensive and extravagant. Voice communications require two or three times the transmission facilities as do record traffic or data. Ensuring voice recognition consumes a large amount of the limited spectrum.

- High-speed data traffic will be widely employed by the year 2000. Coding schemes, error-correction techniques, security, etc., will result in a corresponding loss in the amount of useful information that can be transmitted.

- Using new multiplexing techniques, the channel requirement for multichannel systems should peak at approximately six channels. Forty-eight channel systems should accommodate 99 percent of all future trunking requirements. Packet switching at megabit rates will be prevalent by the year 2000. Data will be processed, however, at much lower data rates.

C.2.1.5 Systems

Respondent: Mr. R. Kulinyi

Comments:

- With respect to the technology areas of LSI for communications/automatic data processing applications such as multiplex systems, displays, and frequency control devices, the primary limitations to future growth lie in considerations related to quality assurance and economics. In many situations, it would be uneconomical to apply LSI technology, particularly when the quantity of an item in the Army inventory may be rather small. For large production runs, the initial low yield achievable with LSI chips would be economically justified. LSI circuitry is inherently complex and, in small quantities, can be quite expensive.

- Quality crystals for frequency control applications in radio sets have achieved good yields as a result of quality control methods that data back to World War II. For crystals used in these applications, the number of parameters that must be controlled is limited as compared to crystals that are to be used in filters. This gives a rough analogy to the present quality assurance problem in LSI applications.

- Once a reasonable level of chip yield is achieved for LSI circuitry, stopping the production line followed by a subsequent start-up will always result in some initial degradation of product quality. Different production lines, operated under slightly different conditions, would necessitate some modification to these chips and the actual yield can only be determined after a minimum learning period. Hence, some degradation of product quality can be expected initially when activating a "second" or previously dormant production facility until "infant mortality" has run its course.

- Training will be a major constraint in the future.

- By the year 2000, data rates of 100 Mb/s will probably be commonplace. Upper limits for tactical data rates, based on requirements, will be in the neighborhood of 30 Mb/s. The eventual TDM 100-Mb/s systems will carry an aggregation of traffic, i.e., intelligence, surveillance, communications, etc.

- Switching rates will have to accommodate data in the Mb/s range by 1985. Separate addressees will receive, extract, and use portions of this megabit stream, perhaps at a rate of only a few dozen bits/sec.

- Solid-state RF generators will be increasingly employed, particularly in transmitter stages such as oscillators, modulators, and final amplifiers.

- Electro-optical communications will be in common use by the year 2000. Ultimate limitations to this technique will be determined by basic quantum mechanics effects. Optical-to-electromagnetic conversion methods will find application in signal processing.

- The growth of SAW technology will be limited by electromagnetic transducer distortion and device efficiency. These devices will compete with crystal filters as candidates for future electromechanical filters. SAWs suffer from many of the defects that limit electromechancial filters, i.e., distortion, overload, dynamic range, and transducer efficiency.

- Future generations of antennas will be smaller and, at the same time, more efficient. This will involve a tradeoff between contradictory requirements. New techniques and improved coupling methods will allow the use of trees, vehicles, airframes, etc., to serve as effective radiators, particularly at low frequencies in the 4- to 7-MHz range.

- The use of vehicles and other metallic structures as antennas of opportunity is complicated by the inability to predict radiation patterns, efficiency, and frequency dependence. This is primarily caused by the lack of uniformity in body electrical contacts which makes each vehicle somewhat different from any other vehicle.

- Helicopters will be employed more frequently as airborne relays to achieve better radio coverage. This will result in more predictable communications.

- By the year 2000, vehicular and manpack radio antennas should be almost completely unobtrusive. Fast frequency hopping and steerable null antenna processors may serve as effective ECCM techniques.

- Future communications systems, particularly mobile subscriber access systems, will have the capability of varying output power to match the mission and technical requirements. This, in turn, will result in a corresponding control over received signal strength, depending on path loss. By the year 2000, the density of net radios will have proliferated to the point where this kind of output power control will be essential.

- The major problem area facing C-E designers over the next 25 years is the effective matching of the equipment to the man. The human operator will be required to operate the I/O devices, turn knobs, read meters, etc.; this requirement dictates an ultimate lower limit to the size reductions that can practically be achieved.

- Superconducting receiver front ends could result in Qs of 1.5 million in certain frequency ranges with correspondingly high receiver selectivity. A major problem area with this approach will be in finding techniques for heat removal and thermal control.

C.2.1.6 Communications Research

Respondent: Dr. F. Reder

Comments:

- The technology areas that are of primary interest to the respondent are:

  - Antennas
  - Optical fibers
  - Communications in built-up areas
  - Ionospheric effects on electronic systems.

- Many military antennas will have become inconspicuous by the year 2000. These small antennas will still retain a wide operating bandwidth. Studies of the interaction of small antennas with their mounting platform are in progress.

- Fast frequency hopping techniques will have matured by 1980.

- Antennas will employ active elements which will permit a wide range of applications. These antennas will be used in both the transmitting and receiving modes.

- Optical fibers offer the advantage of secure and interference-free operation. By 1980, methods will have been developed to detect hostile tampering with fiber optics transmission media.

- The major problems associated with communications in built-up areas, i.e., from basements, beneath rubble, etc., will have been solved by 1990. A growing data base in this area is being collected by local police and fire departments. Existing equipment using new methods of operation will function in this role. The problem of friendly emitters operating in physical proximity to hostile interceptors will be overcome through the use of adaptive techniques to reduce transmitter output power, signal hiding using noiselike signaling to transfer information, and authentication measures to detect enemy spoofing.

- Operators will have to be trained to use their ingenuity in overcoming problems associated with built-up area communications. For example, a small displacement in antenna location can result in sizable increases in signal-to-noise ratios.

- Considerable improvements can be expected in antenna couplers. Coil wraparound techniques can be employed to transform steel structures into effective radiators.

- Complete transmission security (i.e., hidden emission) is a requirement for intercity communications. Signals will be hidden in noise to prevent their detection by an enemy in proximity to the friendly user. Standard encryption techniques will not suffice.

- Considerable research is required as to the effects of ionospheric anomalies on navigation and communications systems. Location accuracy requirements have increased from kilometers to a few meters. These requirements necessitate a new look at the ionosphere.

- Ionospheric studies will not be restricted to the conventional layers but will consider the entire charge space including the plasmasphere. By 1990, the problems associated with scintillation effects will have been solved. This will be particularly important to equatorial and high-altitude regions. Presently, scintillations limit communications and navigation reliability.

- A new phenomenon associated with scintillations must be investigated. The intensity of scintillations has been observed to increase at GHz frequencies, whereas theory would dictate a decrease in this intensity. Spatial and temporal correlation techniques will be employed in an effort to predict scintillation behavior.

- The presence of a gravitational wave structure in the ionosphere and its adverse affect on HF direction-finding systems will be investigated. By 1990, ionospheric soundings taken directly overhead will provide information on conditions far removed from the observer caused by the presence of this gravitational wave structure.

C.2.2 Avionics Laboratory

C.2.2.1 Environment Sensing and Instrumentation

Respondent: Mr. R. Cruickshank

Comments:

- The two technology areas that are of primary interest to the respondent are:

  - Instrumentation
  - Environmental sensing.

- By the year 2000, control panels, displays, switches, and instrumentation will have become integrated, will be modular in construction, will employ digital signaling and addressing, and will be microprocessor controlled. The display will interface digitally with the processor and will operate in an interactive mode. Both engine and flight information will have become integrated and will be viewed on a common flat-panel display.

- The processor will be capable of inserting map symbols, as well as other multilegend data such as target elevations, nature and location of irradiating signals, etc., directly on the display.

- Future integrated control/display panels will be miniaturized, highly reliable, and will consume little power. The flat-panel displays will be fabricated from a solid-state (LED, LCD, light emitting film, etc.) luminescent media.

- Sensors, displays, computational capability, data bus, control switches, etc., will be designed as a common integrated system.

- By the year 2000, 60 percent of the flat-panel displays will be solid-state, 30 percent will be CRT, and 10 percent will be electromechanical. Displays will be of the "heads up" configuration and mounted either on the instrument panel or as an integral part of the pilot's night vision goggles. The pilot will thus be able to view a night scene with superimposed, computer-generated symbology.

- Wire obstacle warning (WOW) systems will have been installed on all Army tactical aircraft by the year 2000. These will permit low light level, nap of the earth flight profiles at altitudes below 50 feet. The pilot will thus be able to safely operate his aircraft as well as effectively discharge his stores in a combat environment.

- 120 inches of total symbology will be available for display at a speed of 1.2 ms to present a complete system/environmental picture to the pilot. Digital multiplexing will be employed to permit simultaneous program control of up to ten different equipments such as aircraft radios, IFF devices, navigation units, etc.

- By the year 2000, solid-state altimeters and low airspeed instruments will have a digital readout and a microprocessor-controlled, flat-panel display. Early models of this equipment will be available by 1990.

- By 1990, the next generation of Army aircraft systems will employ two displays, one for vertical situation indications and the other to present horizontal situation indications. A digital flight direction system will have replaced the analog flight direction system.

- Future generations of Army tactical aircraft, circa 1990-2000, will be configured with a complete suite of environmental sensors to perform such functions as wire avoidance, terrain avoidance, terrain following, precision landing, homing, stationkeeping, rendezvous, etc. Microwave, millimeter wave, and optical wavelengths will be employed. Multifunctional laser devices, operating from 10.6 μm in the case of the CO_2 laser to 0.9 μm for the GaAs laser, will be effective at ranges between 1000 to 1500 feet for use as target designators, distance-measuring equipment (DME), and terminal homing devices.

- Low cost designs for CCD, linear arrays, image intensifiers, and GaAs laser illuminators will be in the inventory by 1985.

- A multifunction, sophisticated, low-level terrain avoidance warning system, using a 10.6 μm CO_2 laser, will be available by 1990. The system offers an excellent potential for high precision terrain avoidance and terrain following.

- An extremely sophisticated night vision capability will be available by 1990 using filtering, detection, and processing techniques that will effectively operate at low power levels to detect wire obstacles in all sky/background environments. The sensor devices will employ either nitrogen or thermoelectric cooling.

- By 1990, the main barrier problem to low-level NOE flight operations, i.e., terrain following and wire obstacle avoidance, will have been overcome.

At altitudes below 50 feet, gradual changes in the terrain and the presence of hanging wires present a harzard to aircraft, particularly at night. The development of sensors, operating at very short wavelengths, that will detect small dimensional structures, such as wires, and gradual changes in the elevation of the terrain, will go a long way towards overcoming this barrier problem.

C.2.2.2 Airborne Systems and Communications

Respondent: Mr. J. Duffy

Comments:

- Airborne communications equipment historically proceeds at a rather slow evolutionary growth rate with separate generations being in service for 20 to 25 years. This trend is expected to continue in the future. Thus, equipments in development in 1976 can be expected to be in operational use in the year 2000 time frame.

- Future generations of airborne communications equipment will be smaller, lighter by an order of magnitude, and individual aircraft will be equipped with a multimode radio capability, i.e., VHF-FM, HF, SSB, UHF, etc. Component designs have followed the overall technology trend from vacuum tube circuitry to transistorized configurations, and finally evolving to LSI chip fabrication. The frequency band of interest to airborne communications designers is currently in the 2- to 400-MHz range, but by the year 2000 this operational band will have to shift upward to the microwave and millimeter wavelengths. Thus, in the 1950s, aircraft radios were large, used vacuum tube technology, weighed in excess of 40 pounds, and there was but one radio set per aircraft. By the 1960s, the operational radios were the AN/ARC-102, AN/ARC-54(FM), AN/ARC-73 (VHF), and the AN/ARC-51 (UHF). In 1966, a new series of transistorized radios was developed, the AN/ARC-114, 115, and 116. We currently have a nap of the earth (NOE) communications test and analysis program to arrive at a candidate system that will provide reliable communications from 0 to 50 km at NOE attitude.

- No replacement is currently planned for HF radio equipment; however, the results of the NOE program may initiate a requirement for a new HF system.

- The overall trend in aircraft radio equipment in the past 25 years has been as follows:

  - Fourfold reduction in weight, from 30 to 8 lbs.

  - Sixfold reduction in size, from 800 to 150 cubic inches

  - Fourfold reduction in power consumption

  - Provision of an additional receiver

  - Incorporation of replaceable PC boards (no adjustment required)

  - Introduction of a rapid retuning capability

  - Improved stability

  - Introduction of better frequency synthesizers.

- Future aircraft radios, circa 1985, will have extended storage life, better response, frequency selectivity characteristics that will improve undesired signal rejection from 50 to 80 dB, and enchanced receiver sensitivity. Compatible automatic test equipment will have been developed.

- The AN/ARC-116 will be replaced by the AN/ARC-164 in an evolutionary process; the latter radio can be expected to remain in the inventory through the year 2000. This radio uses both solid-state and IC technology, small components, and state-of-the-art designs. By the year 2000, all Services will be using the same airborne radio systems. Future changes to these radios will be made on an evolutionary, incremental basis with no wholesale replacement being permitted.

- The AN/ARC-51 will be in the field beyond 1980. The AN/ARC-114 will be replaced by the SINCGARS family in the 1986 timeframe. The SINCGARS radios will become the universal FM airborne radio equipment by the early 1990s. Frequency hopping will be used in these sets as an ECCM measure. By 1990, airborne radios will employ all solid-state designs.

- Future aircraft radio procedures will see the employment of short, preplanned messages to conserve channel capacity and minimize hostile intercept. Slow-speed data may be employed to further conserve the limited spectrum available. Simple preformatted messages will be transmitted by the pilot by activating an appropriate switch(es).

- Satellite communications to tactical Army aircraft is not expected by the year 2000. Recourse to HF for beyond line-of-sight, NOE flight profiles will be required through the next 25 years.

- By the year 2000, aircraft systems will have become completely integrated and will be processor controlled. The on-board computer will completely control the multiple radios, to include automatically setting up the transmit and receive frequencies. This integrated aircraft control system (IACS) will employ digital control signals for all avionics systems, to include IFF, communications, etc., and the control system will be automatically adaptable to the changing operational environment.

- By the year 2000, airborne systems will be completely modular, employ standardized interfaces between components, be computer controlled, utilize common message formats, and use effective error-correction techniques. LSI will be extensively employed. The pilot will be able to switch from one preset frequency assignment to another without knowing or caring which specific frequency assignment was being employed. Channel selection, based on channel availability, would be accomplished by the processor. These features will have considerably increased the complexity of avionics systems by 1990.

- By 1990, aircraft radios will have a complete self-test capability. The test equipment will isolate faults to the lowest replaceable unit.

- By the year 2000, the technology will be available to produce major radio subsystems on a single chip. Further size reduction will no longer be a requirement. At this point in time, the radio could well become a throwaway item.

- The major driving force in the use of ICs in aircraft avionics systems is cost as reflected in chip yield. A 3-percent yield can be tolerated if the chip production volume is large enough. For a manpack radio, this criterion presents no problem. For aircraft radios, where production volume is inherently low, use of IC technology may not be justified from an economic viewpoint. The total population of aircraft radios for all Services will probably not exceed 25,000 units by the year 2000. This is a small number compared to the commercial market for airborne digital radios.

- A digitized airborne intercom control system will be employed in Army aircraft by 1990. Interconnecting digital circuitry, using fiber optics transmission media, will be cheaper and will provide bandwidths from 1000 to 15,000 GHz.

- Aircraft navigation systems that will be in use by the year 2000 include JTDS, PLRS, and the GPS. These systems will employ a master control system and will be capable of accurately locating all friendly elements on and above the battlefield.

- Night vision devices integrated with dynamic, computer-controlled map displays will be standard avionics equipment by the year 2000. Fiber optics cables will be employed as the interconnecting media. Existing aircraft systems, circa 1976, will begin a retrofit cycle, during which this equipment will be installed, commencing in 1990.

C.2.2.3 <u>Air Traffic Management Systems</u>

<u>Respondent</u>: Mr. J. Saganowich

<u>Comments</u>:

- The technology areas that are of primary interest to the respondent are:

  - Instrument landing systems
  - Air traffic management
  - Aircraft communications equipment

- Interfacing civil systems
- Ground control approach (GCA) radars
- Air traffic control
- Transponders
- Computer control techniques
- Displays
- Information processing.

- Standardization of systems, signaling formats, procedures, etc., will continue to be a significant goal in the future.

- Technology poses no problems to the recently acquired executive management responsibility for the DOD portion of the national microwave landing system.

- Future developments will tend to move to higher frequencies, i.e., Ku band, from 15.4 to 15.7 GHz.

- Future test systems will be required to function over the entire radio spectrum. This equipment will be capable of handling a variety of subsystems, will be preprogrammable by the simple insertion of cardlike elements, and will print out specific corrective measures to be taken by operators. By the year 2000, automatic test equipment will have the capability of measuring the important parameters associated with spread-spectrum techniques.

- Adoption of U.S. standards by the international community, such as those which apply to signal formats, will have an important impact on future testing requirements.

- By 1990, automatic test centers will have been established for the testing and repair of electronic avionics equipment.

- The Position Locating and Reporting System (PLRS) currently under test will be upgraded from one master and 17 user stations to one master and 64 user stations. This system will be digital, will provide precise ranging information, and will employ autocorrelation and long pseudo-random sequencing techniques. COMSEC will be implemented.

- Future automatic test equipment will be capable of differentiating between equipment problems and poor propagation conditions. This equipment must indicate incipient system potential for failure.

- The basic PLRS components will be employed in both aircraft and ground vehicles.

- There will be considerable future advances in the pilot's control and display panels. Indications will be furnished as to such parameters as distance, steering information, etc.

- IFF equipment will continue to be designed for L-band operation.

C.2.3 Electronics Technology and Devices Laboratory

C.2.3.1 Solid-State Circuits

Respondent: Mr. Sproat

Comments:

- The technology areas that are of primary interest to the respondent are:

  - Signal processing
  - Design of circuits
  - Microelectronics
  - Charge-coupled devices.

- Increased use of linear ICs can be expected in the future for handling high-frequency (100 MHz - 1 GHz) analog signals.

- By 1985, CCD memory devices will be widely used in the field and will no longer be a laboratory curiosity. CCD memories may emerge as a third level of memory, located between the mainframe memory and the bulk auxiliary memory. CCD memories will find wide application in image intensifiers, signal processors, infrared detectors, etc.

- CCD technology has the advantage of permitting the handling of signals on an analog basis, but, at the same time, utilizing the capabilities of digital timing, synchronization, etc. Thus, the best of the analog and digital worlds can be combined in these devices. The CCD devices operate on signals in an analog format. Timing, control, and master clock signals would all use digital signal formats. No A/D or D/A converters would be required.

- By 1980, it will be possible to add the control circuits to the CCD memory chips providing a very compact, low cost design. By 1985, the achievable resolution on silicon substrates will permit high-density programmable CCD configurations on silicon chips of a few hundred mils square. This will represent a slight increase in size over non-programmable devices.

- In order to be cost effective, current custom-built CCDs will evolve to more universal designs. Until this evolution takes place, it will be difficult for CCDs to compete in the digital world.

- In order to amortize the cost of custom monolithic LSI digital signal processing devices, such as used in radars or SINCGARS, the production volume must be in the neighborhood of 10,000 to 100,000 devices. Through use of computer-aided design, this required production volume will be continually lowered in future years. When size and weight are of paramount importance and cost is secondary, custom LSI in volumes of hundreds or even tens of units may not be uncommon.

- By 1985, tapped CCD delay lines will be used for moving target detection and range/velocity discrimination. Tapped delay lines would be used to satisfy the moving target indication (MTI) function in which stationary target returns would be cancelled out.

- By 1985, solid-state ICs will be widely employed in matched filters, spread-spectrum processors, correlators, and other programmable devices. High resolution spectrum analyzers, using chirp-Z or Fourier transformations to operate on sampled data, will be able to detect and analyze frequency responses over wide spectral ranges. At the low frequency end of the spectrum, this circuit technology will permit bandwidth compression applications, such as would be required in vocoders.

- The major barrier problem that must be overcome with the silicon CCDs is the thermal leakage current which tends to saturate the charge centers and wipe out the stored data. This problem area limits low-frequency operation where the sampled signal must be retained for a long time. This storage time is highly sensitive to temperature changes and tends to half for every 8° Celsius rise in temperature. In the case of the seismic and acoustic detectors used in the Remotely Monitored Battlefield Surveillance System (REMBASS), the frequencies involved are in the neighborhood of 1 to 100 Hz and leakage current becomes a fundamental limitation.

- By 1990, CCD arrays will likely be fabricated using GaAs. This will overcome the current CCD limitation pertaining to speed and storage times. Speeds exceeding 1 GHz and storage times exceeding 1 minute can be expected.

- CCD memories, although currently requiring serial access, have certain advantages over RAMs. The CCD arrays are one-half to one-quarter the size in bits/mil^2 as MOS RAM. Thus, a 16-k bit CCD would occupy the same chip area as a 4-k bit RAM. The technologies are roughly equivalent, the chip areas are comparable, and the costs are the same. For computer applications, the implication is that the size could be reduced by one-quarter or that four times the memory could be contained in the same space. The conservative approach would be to use the more familiar RAMs, but if a two to three times cost advantage can be derived, a switch can be expected to the new CCD computer memory.

- The access times for the CCD memory are inherently slow. Bit lengths of 1000 bits or more must be serially scanned before a desired address is obtained. This results in access times of tenths of microseconds. MOS RAMs will, therefore, continue to be used in increasing numbers when fast access times are required.

- The RAM memory will have replaced the older core memories in the vast majority of new equipment by 1985 providing capacities of from 10^4 to 10^6 bits per device.

- The CCD memory will probably evolve as an intermediate memory between the fast mainframe memory and the bulk tape or disc memory. Again, the CCD memory offers a four to one size advantage when compared to high-density N- or P-channel memories.

- MNOS memories will likely have replaced the digital disc memories by 1990. These memories are non-volatile and do not lose information with loss of power. They represent the semiconductor equivalent of tape memories.

- CCD memories are dynamic, have very low power dissimpation, and can handle analog signals over wide dynamic ranges.

- There will be a rapid growth in ultra-high-speed logic ICs, such as I^2L and silicon-on-sappline (SOS)/CMOS devices. By 1990, GaAs logic will find increasing use in ultra-high-speed (1-2 GHz) digital processors.

- The same technology found in the units under test will also have to be employed in future automatic test systems. Thus, SOS techniques, providing high speed, low power consumption, and high density will be employed.

- By 1985, microprocessors for use in secure communications systems will have been fielded.

- By 1990, CCD signal processors will have become a standard product for use in several Army equipments.

- The evolution of IC materials have been from PMOS to NMOS to bulk CMOS to I^2L to SOS and eventually to GaAs. In comparing I^2L with SOS, I^2L has higher packing densities and both linear and digital circuit configurations can be placed on a single chip.

- Future growth in LSI technology will lead to replaceable, throwaway modules; highly complex designs; and configurations that occupy less space and perform more functions.

- The equipments of the year 2000, such as the AN/URC-78 derivatives, will employ multichip hybrid circuits in hermetically sealed packages. Monolithic memories will be widely used and subsystems using microprocessors will possess a self-test capability.

C.2.3.2 Power Sources

Respondent: Mr. D. Linden

Comments:

- The major metrology problem associated with batteries is the ability to obtain meaningful predictive indications of potential battery life.

- Power supplies for the larger automatic test systems are not considered a problem as these systems will receive power from dedicated power sources.

- Future automatic test equipment will employ pulse techniques to determine battery charge/discharge characteristics.

- Future test equipment should be capable of predicting battery behavior in any operational application.

- To adequately test storage batteries it will be necessary to know the battery's previous history. Storage batteries will continue to be charged separately from the equipment with which they are used.

- By 1990, batteries will have become more standardized and single battery types will be capable of use in many different equipments.

- Future radio equipments, such as the AN/PRC-77, will have battery chargers as part of the basic assemblage. These radios will contain automatic test equipment that will be capable of testing the batteries.

- Future battery designs will be more closely controlled to make their behavior more predictable. Thus, batteries of any type made by a number of manufacturers will all exhibit the same discharge characteristic. The objective would be to achieve a flat voltage discharge characteristic.

- Presently, the inorganic lithium battery shows the most promise for the future.

C.2.4 Combat Surveillance and Target Acquisition Laboratory

C.2.4.1 Special Sensors

Respondent: Mr. J. Schoening

Comments:

- It will be too expensive and time consuming in the future to send repairable circuit boards back to a depot maintenance support level or to the manufacturer for repair. Built-in test equipment will be required that can isolate and diagnose faults to the component level. Such equipment will be needed mainly at general support locations.

- Computer-controlled automatic test equipment will be available to calibrate and test all types of C-E equipment by 1990. Extensive use will be made of interface boxes to couple the equipment to the processor.

- The hardware that is at the advance development or engineering development stage today will be the equipment in the field from the mid-1980s to the year 2000.

- Radio data links for transmitting sound-ranging data will be in the field by 1985. This equipment will be first introducted in 1979.

- Some circuit cards will be so expensive that a capability must be provided for their repair.

- A major maintenance problem exists with current high-density LSI configured equipments in the unreliability of soldered connections. Automatic test equipment of the future will have to diagnose and locate this type of fault.

- Highly sophisticated automatic test equipment is already being employed on production lines. For example, microphones can be automatically tested to give a readout of the frequency versus sensitivity characteristic in a matter of minutes versus several hours under manual techniques. Much of this capability, such as spectrum analyzers, will be developed by industry without government sponsorship.

- As long as tube artillery remains in the inventory, accurate meteorological data will be required. For the 8-inch and 155-mm artillery weapons, meteorological data over an altitude of 12 km will be required with an accuracy of ± 1 knot for wind velocity and ± 5 mils for angular data. Temperatures will have to be measured to within a degree Celsius.

C.2.4.2 Photo-Optics

Respondent: Ms. M. Levy

Comments:

- The future trend in photography will be towards faster, dry film processing techniques. Night photography will receive considerable emphasis.

- By 1990, computer-controlled automatic test systems will be widely employed for testing electronic auxiliary equipment associated with camera systems.

- The combining of image intensifiers with camera subsystems will be common by 1985 for night applications.
- The use of holographic techniques will require new testing procedures.
- By 1990, optical signal processing will be widely employed.
- By 1990, lenses will be designed and tested using computer-aided techniques. Computers will be employed for the predictive analysis of photographic equipment and films.

C.2.5 Communications/Automatic Data Processing Laboratory - Center for Tactical Computer Sciences (CENTACS)

C.2.5.1 Computer Sciences

Respondent: LTC. A. Salisbury

Comments:

- The systems that will be in the field from 1980 to 2000 will contain today's (or even yesterday's) technology. These systems include TACFIRE, battery fire control systems, Army Security Agency (ASA) equipment, the AN/TSQ-73, QCS, etc.
- The QCS, redesignated the Tactical Computer System (TCS) may well become the principal subsystem for the TOS. As such, it could constitute a terminal for the TOS.
- Future systems will contain BITE. The EQUATE (ATE) concept will complement BITE for higher echelon maintenance facilities where repair is actually performed.
- A major product improvement program for the future will result in the replacement of processors with emulation devices. This will present an entirely new set of requirements for automatic test equipment. The emulator subsystem will provide the same computer functional performance, will operate on current software, and will be compatible with existing computer systems. This

approach will broaden the competitive base for such items as the control data processors in the TACFIRE system. Considerable economic advantages should result.

- The increased use of LSI will assist in eliminating the current problems associated with the poor reliability of connectors.

- Because of the large inventory of older state-of-the-art radios, the manufacture of germanium transistors will have to be continued into the future.

- The choice of emulators to replace processors will drive down weight and size, add more memory, and result in a general increase in functional capability.

- Continued digital message device (DMD) development/improvement will reduce the size and weight of manpack devices. These devices will be used by forward observers, will contain BITE, will employ customized LSI circuity, and will be carried with the radio. The weight reduction currently predicted would be from 17 to 10 lbs. This is still considered to be too much of a weight penalty. Future improvements can be expected.

- By 1985, COMSEC devices will have been integrated as modules within the basic radio sets and ADP terminals.

- The use of microprogramming emulation will alter ILS concepts. The LRU can be a form-fit-function module as LSI permits CPUs to be put on a single card. Piece-part logistics below the card level will be complicated if different internal designs are used. Throwaway cards will solve this dilemma when economics permit.

- Maintenance concepts will be revised in the future. This will result from the widespread use of microprocessor emulators.

- Electronic circuitry will have replaced most of the electromechanical control devices by 1990.

- Serious consideration is being given to a throwaway concept as opposed to the conventional methods embodied in the various echelons of maintenance. The widespread use of LSI technology would result in the elimination of test points and make access at the component level quite difficult.

- The future use of fault tolerant LSI/MSI designs will make individual component failures, such as a logic gate, rather inconsequential. Equipments will be able to detect these failures and make automatic component substitution or reroutes under processor control. Redundancy inherent in circuits will further reduce the need for substitutions.

- Software maintenance will remain a major problem. Failures or deficiencies in software packages will be reconguized as being as important as hardware failures. Latent deficiencies in software that are not discovered until subsequent deployment must be correctable by delivering new software to the field from a central software control facility. Future test equipment will have the capability of determining whether the failure mode is occurring in the hardware or software. Combinations of failure modes will also be detectable in real time.

- Future automatic test equipment will set up test routines under microprocessor control.

- Training of personnel who are capable of servicing computer hardware and software will remain a serious problem. Replaceable plug-in modules, with associated BITE that provides a go/no go indication will ease this problem. Circuit board repair (when throwaway is not economical) will either be accomplished at general support, depot, or perhaps by the manufacturer. Future systems will be designed to be more fault tolerant. A high degree of component and circuit redundancy will be employed.

- By the year 2000, highly sophisticated, small packaging techniques will be common in militarized C-E equipments. As requirements change, these highly flexible systems will be adaptable without recourse to major system replacement. Future systems will be totally integrated.

- The future widespread use of LSI will result in lower costs and should allow some collapsing of the development cycle. Throwaway devices will have become a practical alternative to costly, time-consuming repairs.

- The rapid growth of new technologies may drive corresponding changes in doctrine, i.e., the employment of artillery may have to be redefined.

APPENDIX D

PROJECTED EQUIPMENT CHARACTERISTICS

APPENDIX D

PROJECTED EQUIPMENT CHARACTERISTICS

This appendix describes the uses and general characteristics of C-E equipment that will likely be fielded during the 1985-2000 time frame. Four generic equipment categories were considered during this study:

- Tactical/strategic communications
- Avionics
- Target detection and acquisition
- Electronic warfare (EW).

General trends in equipment development and usage for each category are discussed followed by descriptions of several typical equipment items within the cateogry that are expected to be fielded during the time frame of interest. Since it was impossible to detail all equipment items likely to be available, detailed descriptions are provided only for items considered representative of the entire category which are likely to be impacted by technological advances.

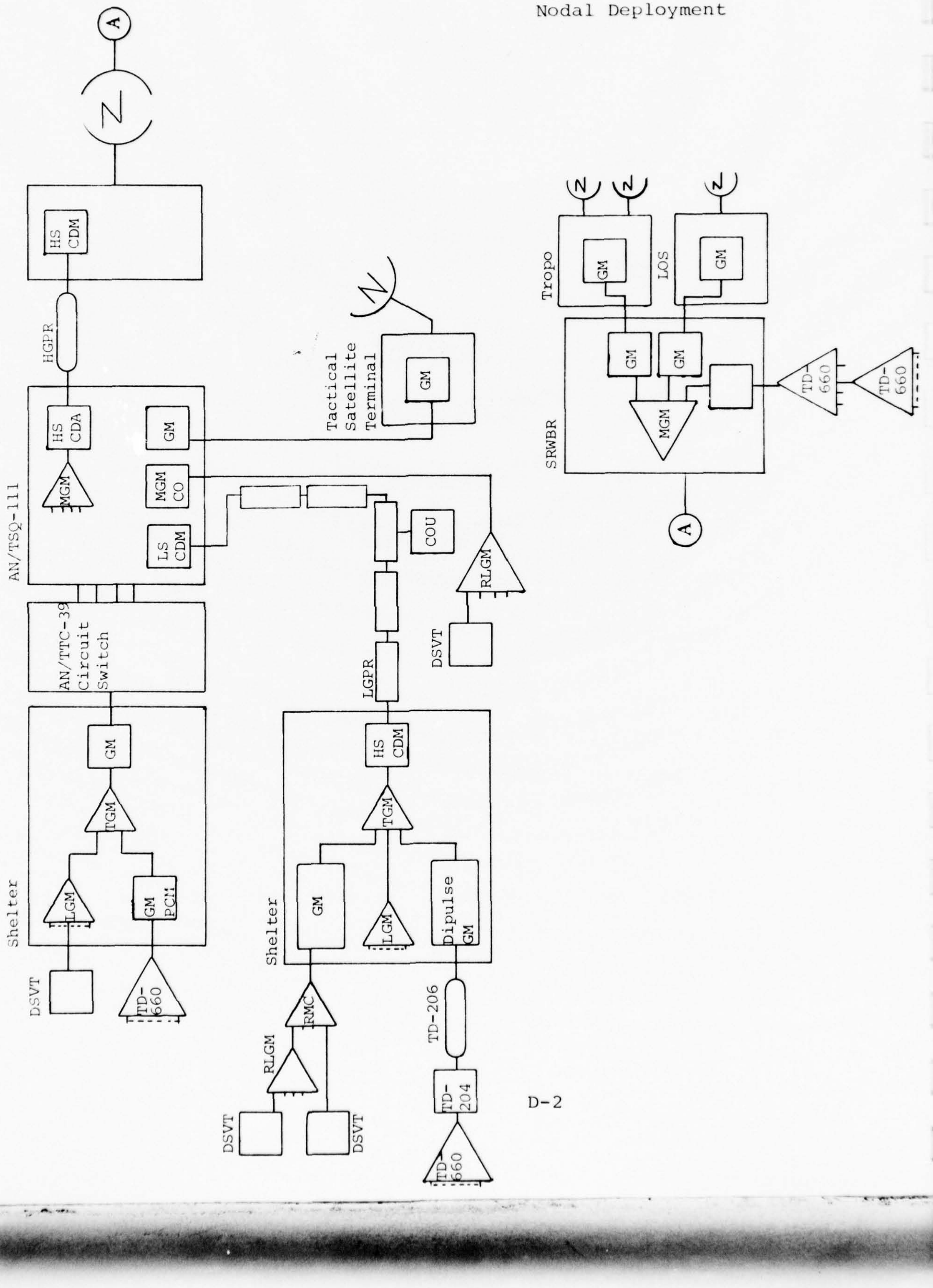
D.1 TACTICAL/STRATEGIC COMMUNICATIONS EQUIPMENT

In general, the equipment being developed under the TRI-TAC Program will become the standard for providing both strategic and tactical switched communications. TRI-TAC covers a wide range of equipment types, including:

- System control
- Switching
- Multiplexers and modems
- Transmission
- Subscriber terminals.

Fielding of this equipment will begin by 1985. The TRI-TAC equipment will gradually replace the current inventory equipment until these equipments comprise nearly the entire switched communications inventory by the year 2000. A typical TRI-TAC nodal deployment is shown in Figure D-1.

FIGURE D-1
Typical TRI-TAC
Nodal Deployment



In addition to TRI-TAC equipment, the SINCGARS family of net radios is expected to be fielded during the 1985 time frame. The SINCGARS family will, by 2000, replace all current inventory net radios.

The following subsections describe the functions and characteristics of several of these equipment items.

D.1.1 System Control Equipment

Four hierarchical levels of control have been defined for the TRI-TAC Program:

- Communications System Planning Element (CSPE)
- Communications System Control Element (CSCE)
- Communications Nodal Control Element (CNCE)
- Communications Equipment Support Element (CESE).

It appears that only the CSCE and CNCE will require significant hardware development. The CESE is peculiar to each prime equipment item and the CSPE will probably only require remote terminals off the CSCE processor.

The CNCE will provide dynamic control of all equipment located at a communications node. CNCE functions include:

- Monitoring equipment status
- Combining/decombining internodal trunks and trunk groups
- Directing equipment repair and maintenance.

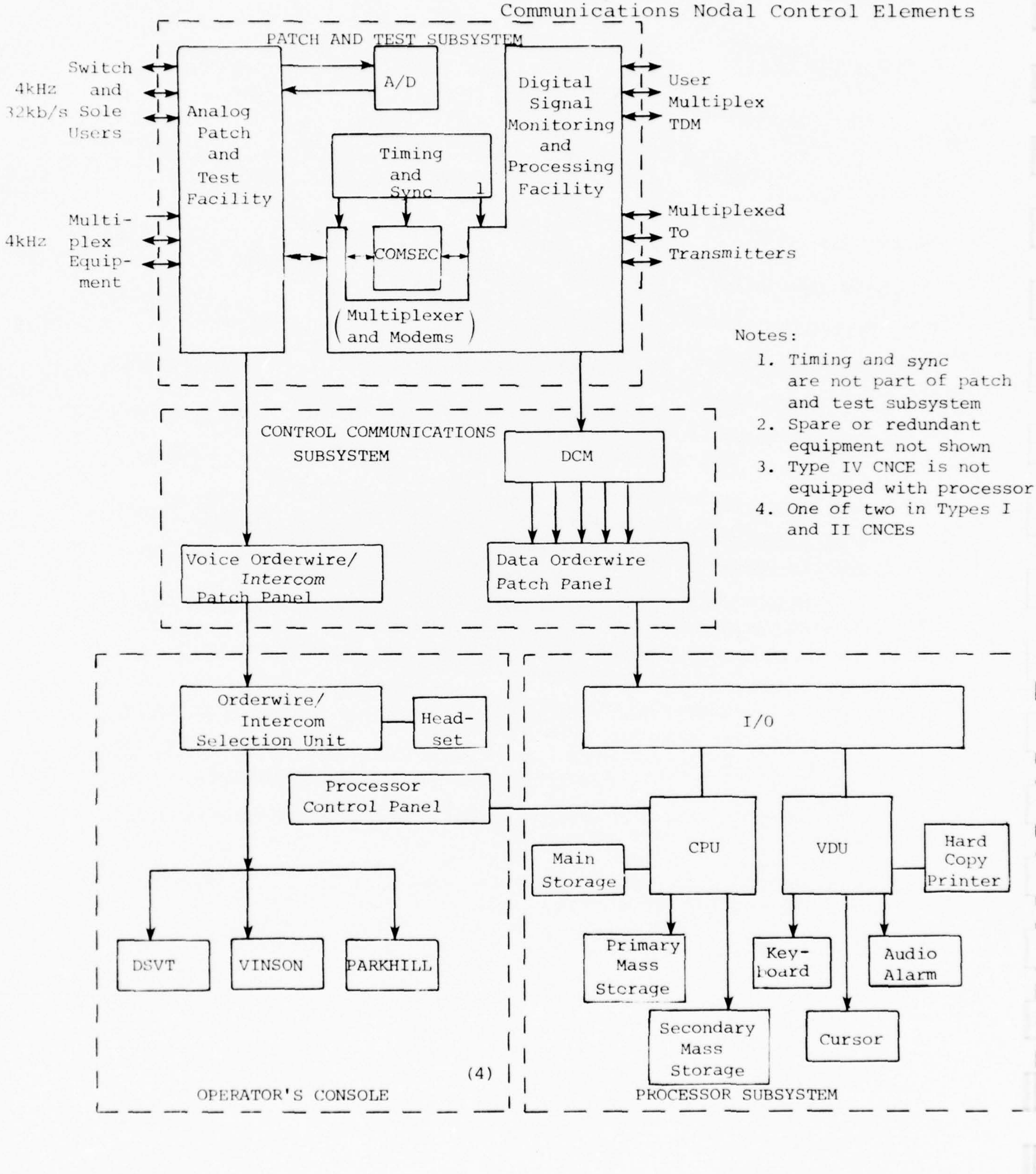
A simplified block diagram of the CNCE is shown in Figure D-2.

The CSCE is responsible for the control of a communications network containing several CNCEs and their associated switches. The CSCE does not require large amounts of multiplex equipment but does contain three processors.

D.1.2 Switching Equipment

The automatic switching equipment being developed under TRI-TAC will begin to be fielded by 1985. By 2000, automatic digital switches are expected to replace virtually

FIGURE D-2
Simplified Block Diagram of
Communications Nodal Control Elements



Notes:

1. Timing and sync are not part of patch and test subsystem
2. Spare or redundant equipment not shown
3. Type IV CNCE is not equipped with processor
4. One of two in Types I and II CNCEs

all present inventory switches. Switching equipment being developed runs from the large central office (AN/TTC-39 and AN/TTC-42) to small, all-digital switchboards (SB-3864 and SB-3865). A block diagram of the AN/TTC-42 is shown in Figure D-3. Automatic switching design relies heavily on processor and memory storage technology and will be most affected by changes in these areas.

D.1.3 Modem/Multiplexing Equipment

TRI-TAC is developing a family of digital group multiplexers and modems (DGM) to operate in future digital communications system. This equipment includes:

- Loop group multiplexer (LGM)
- Trunk group multiplexer (TGM)
- Master group multiplexer (MGM)
- Remote loop group multiplexer (RLGM)
- Remote multiplexer combiner (RMC)
- Group modem (GM)
- Cable driver modem (CDM) (high and low speed).

This DGM equipment allows the multiplexing of 32-kb/s channels up to 18.75-Mb/s rates. In addition, both data and voice orderwires can be inserted.

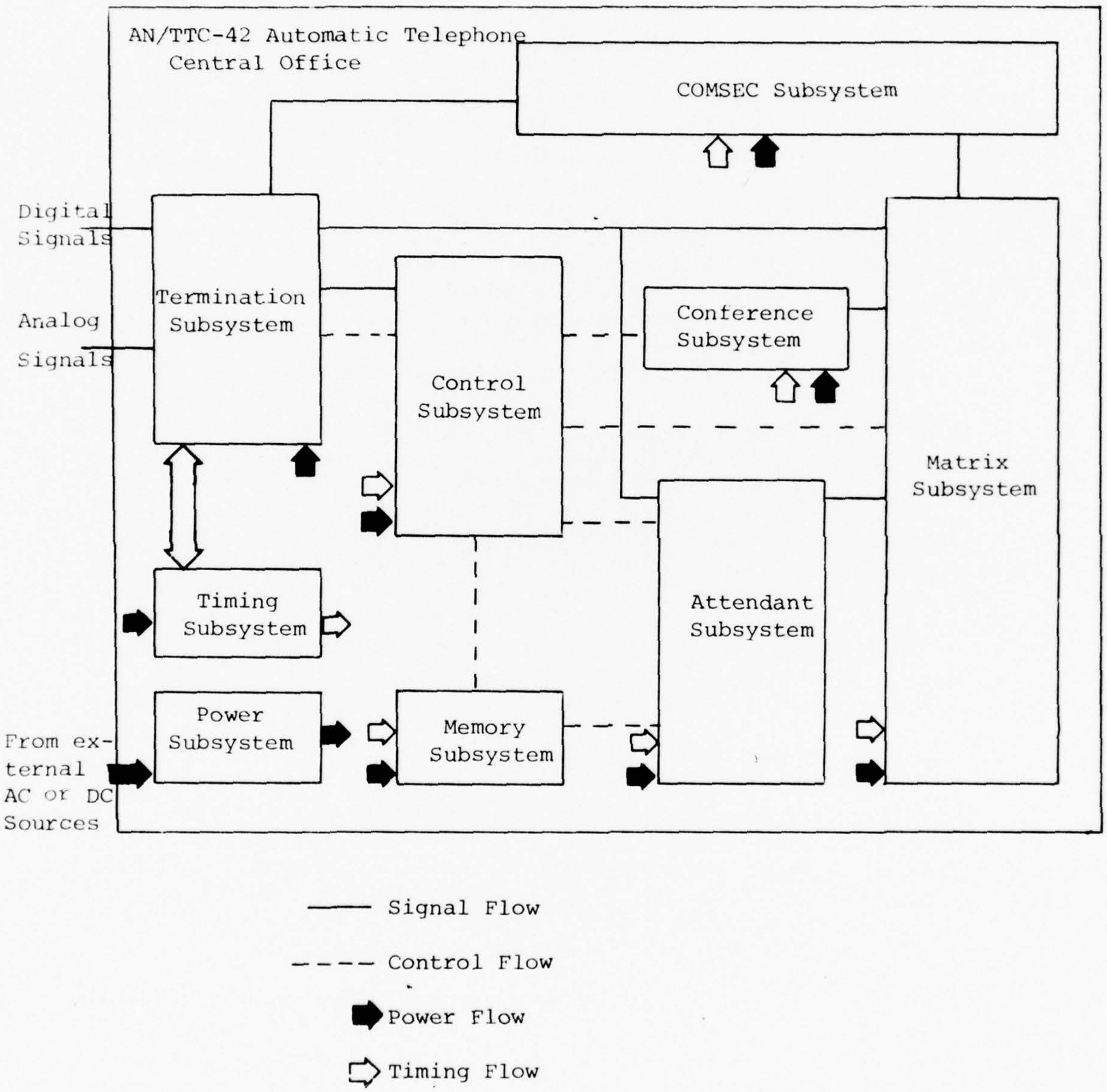
Figure D-4 shows a block diagram of the TGM which is representative of other members of the DGM family. The TGM accepts up to four digital group inputs and multiplexes them into a single bit stream with a rate of up to 4.096 Mb/s. Two of the group inputs can have rates of up to 2.048 Mb/s; the other two can have rates of up to 1.024 Mb/s. The sum of the input rates cannot exceed 4.096 Mb/s.

D.1.4 Troposcatter Radio Terminal

Despite the increasing use of communications satellites, much of the future "long-haul" tactical and strategic communications will be transmitted using troposcatter radio terminals. TRI-TAC is presently developing a family of digital tropo terminals (AN/TRC-170). A simplified block diagram of the AN/TRC-170 is shown in Figure D-5.

The main feature which distinguishes the terminal from analog terminals is the use of DGM equipment and a digital tropo modem at baseband. The RF portion of the terminal is basically the same as other similar analog terminals.

FIGURE D-3
Simplified Block Diagram
of AN/TTC-42



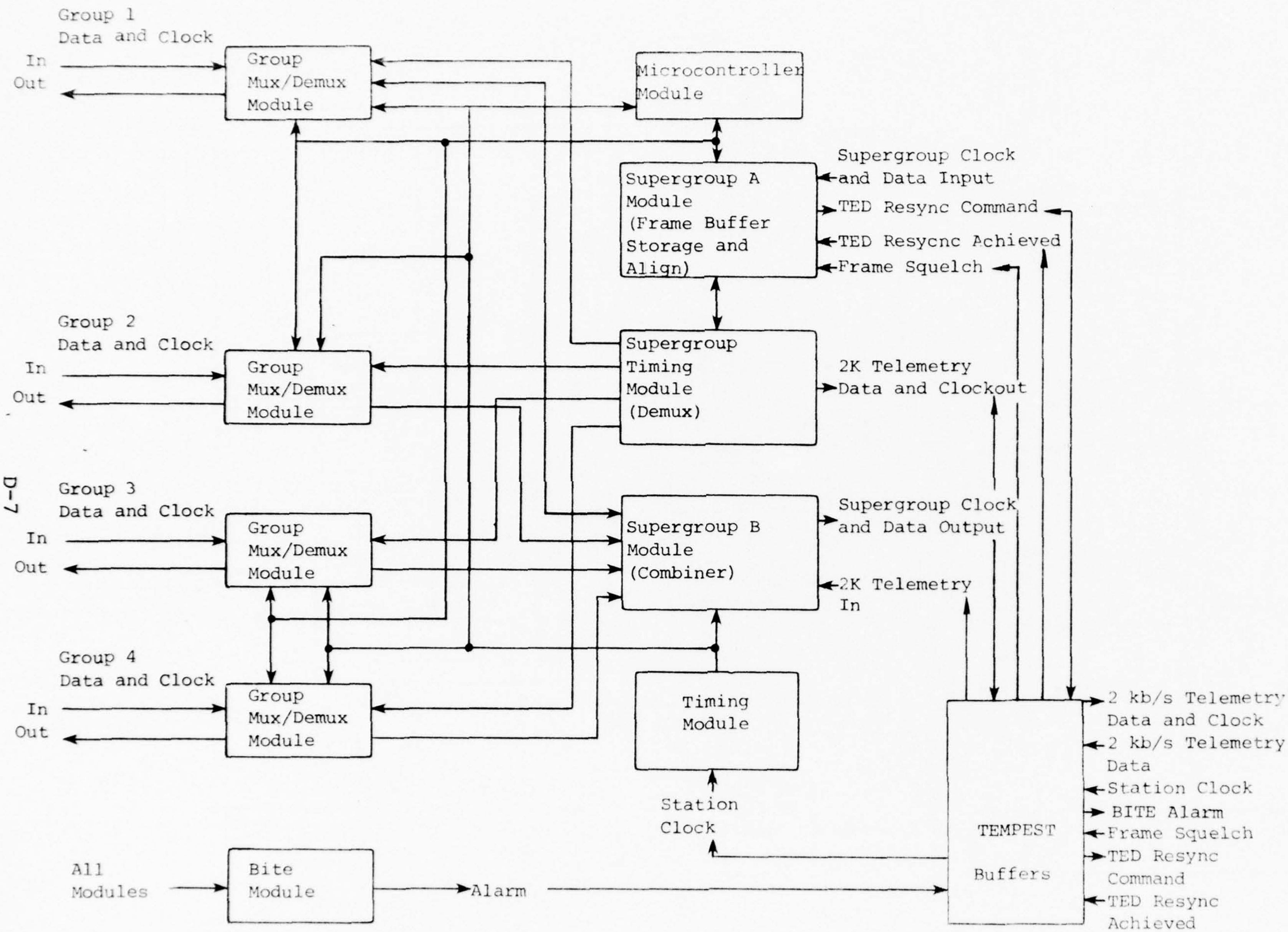
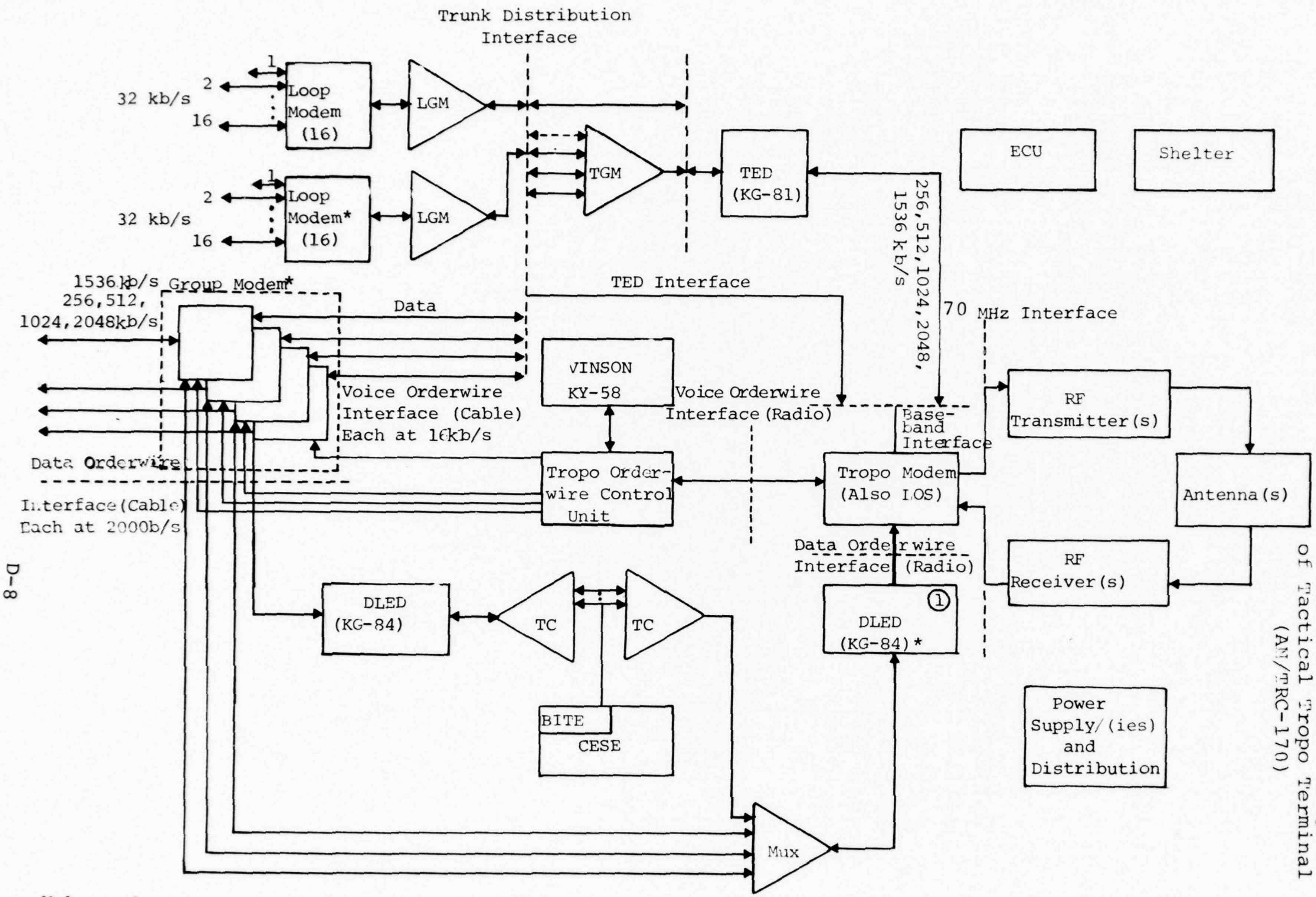


FIGURE D-4
Block Diagram of Trunk
Group Multiplexer

FIGURE D-5
Simplified Block Diagram
of Tactical Tropo Terminal
(AN/TRC-170)



Values of typical system parameters:

Operating Frequency: 1 to 5 GHz
Output Power: 1 to 10 kW

Bandwidth: 15 MHz
Data Rate: 0.1 to 5 Mb/s

The ECCM capability of the AN/TRC-170 is currently not well defined. Depending on the exact approach used, testing of the ECCM equipment may require sophisticated hardware and software.

D.1.5 Fiber Optics Transmission Equipment

It is projected that, by 1990, fiber optics cable will be used to interconnect major system elements in proximity. The first application of fiber optics cable by TRI-TAC will be to replace the coaxial cable used in high-speed data transmission between the AN/TTC-39 and CNCE and between the CNCE and short-range wideband radio. A simplified block diagram of a fiber optics cable transmission system is shown in Figure D-6.

Optics technology is advancing rapidly. Since TRI-TAC is not presently developing a fiber optics transmission system, the exact technology used in this system is uncertain.

D.1.6 Net Radio

The Army is currently developing a single-channel ground and air radio system (SINCGARS) to be fielded during the 1985 time frame. By 2000, various versions of SINCGARS are expected to replace most net radios currently in use including:

- AN/PRC-77
- AN/VRC-12
- AN/ARC-114.

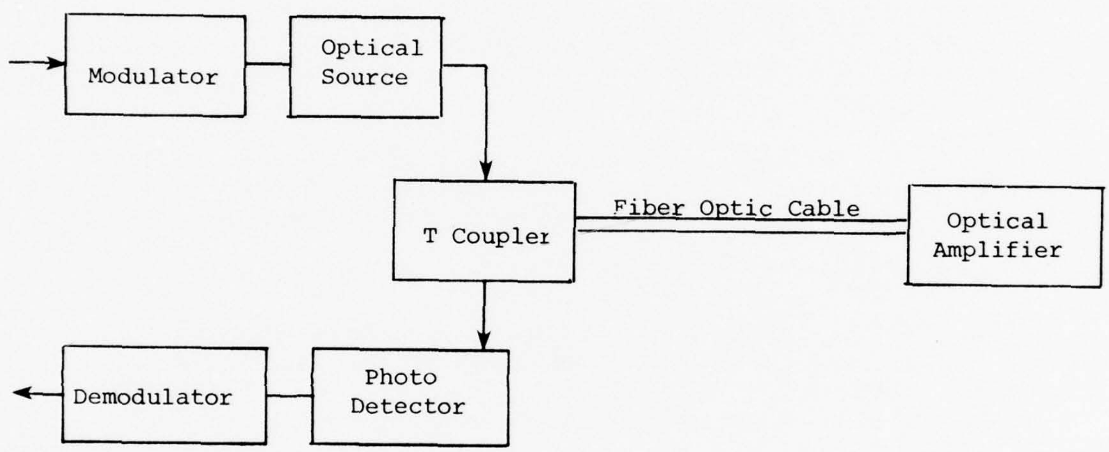
Included in the development is an ECCM module to be provided to selected users.

A simplified block diagram of a SINCGARS radio is shown in Figure D-7. Although the specific technologies to be used in this equipment are unknown, no new exotic metrology requirements are expected, except possibly in the area of ECCM. Testing of a frequency hopping modem would probably require an automatic test facility.

D.2 AVIONICS EQUIPMENT

Avionics equipment is in the process of changing from discrete equipments, each having dedicated sensors and displays, into an integrated system which inputs shared sensors to a central processor and uses a single display to convey information to the pilot. Figure D-8 shows a block diagram of a typical flight indicator/display system.

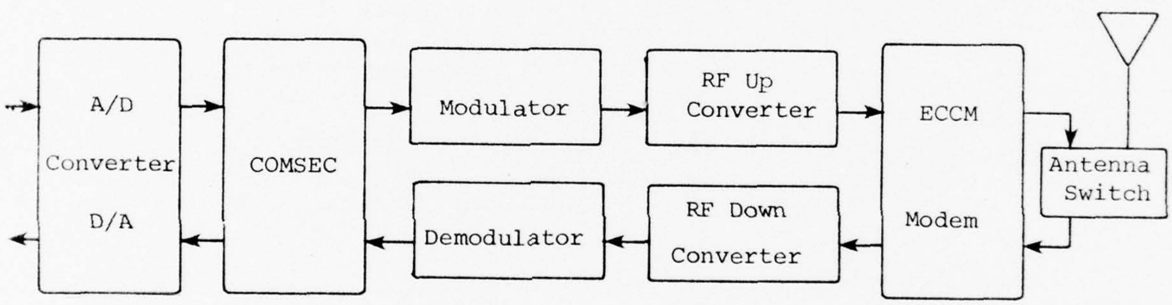
FIGURE D-6
Simplified Block Diagram of
Fiber Optics Cable
Transmission System



Values of Typical System Parameters:

- Operating wavelength - 1 μm
- Optical power - 5 mW
- Data rate - 1 to 1000 Mb/s

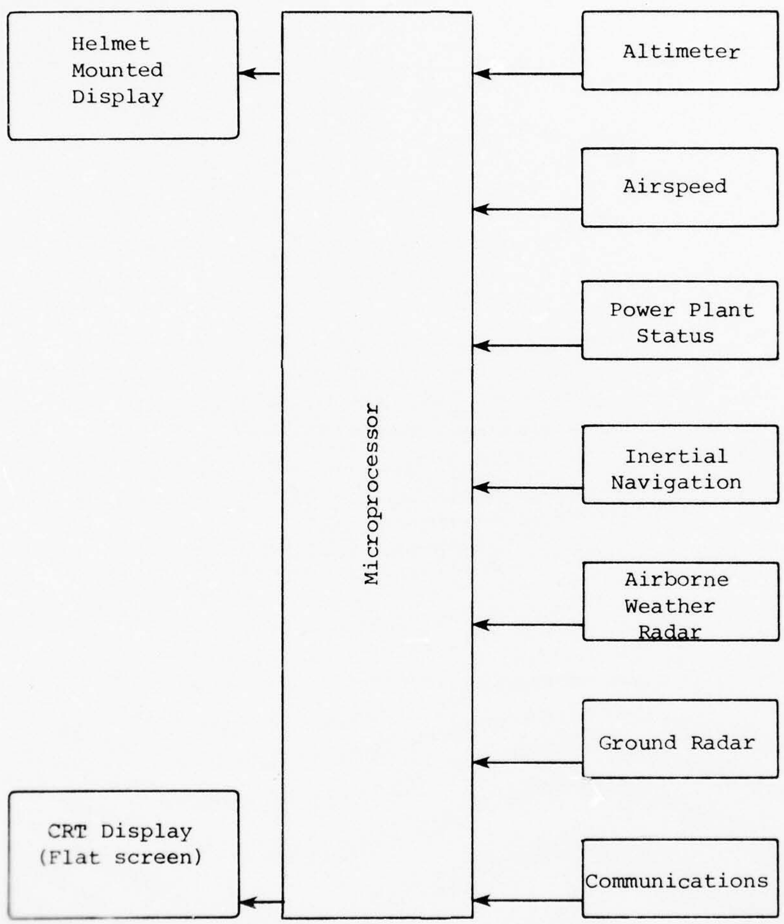
FIGURE D-7
Simplified Block Diagram of
Typical Net Radio (SINCGARS)



Values of Typical System Parameters

- Operating frequency - 30 to 88 MHz
- Output power - 10 to 100 watts
- Data rate - 16 kb/s

FIGURE D-8
Simplified Block Diagram of
Flight Indicator/Display System



Coupled with the trend to an integrated avionics system and the subsequent increased use of digital signal processing will be the increasing use of fiber optics cable in place of metallic cable. Use of fiber optics cable will significantly reduce the weight associated with internal signal transmission, an important consideration when designing airborne systems.

The following subsections describe several items of avionics equipment likely to be in the field in the 1985-2000 time frame.

D.2.1 Distance-Measuring Equipment

Distance-measuring equipment (DME) systems are transponder systems used for airborne range measurements. Used in combination with a vertical omni-range (VOR) facility (e.g., TACAN), DME provides a complete rho-theta position fix.

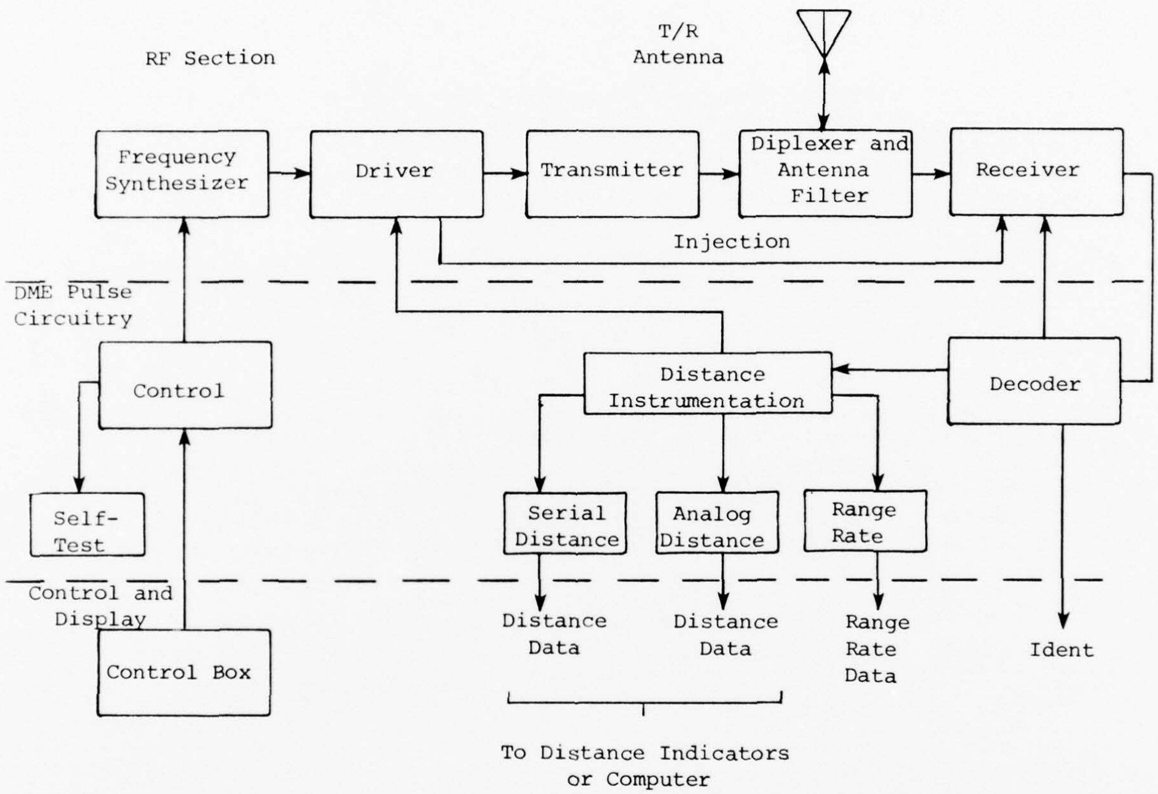
DME is a pulsed interrogator-transponder system operating in the 960-1215 MHz band. Interrogations from an aircraft are answered by a ground transponder; the elapsed time between interrogation and reply is converted to a distance reading between aircraft and ground station by the airborne unit. Figure D-9 is a simplified block diagram of an airborne interrogator/receiver.

Performance parameters of DME ground and airborne equipment are not expected to change significantly before 1985. Technological advances in DME are not expected to create testing problems for DME fielded in the 1985-2000 time frame.

D.2.2 Surveillance Radars

Radar surveillance is the primary means by which the modern air traffic control system maintains safe separation of aircraft and coordinates flight planning. The primary method of obtaining multiple-target range information in the presence of stationary, clutter-producing targets is to combine the techniques of pulse and CW radar to produce moving-target indicator (MTI) or pulse-Doppler radar. Range information is obtained by measuring the two-way propagation time of the transmitted pulse and the received echo, while velocity is determined by extracting Doppler information by comparing the transmitted and received pulse frequency spectra. An important requirement of all Doppler radars is the coherent detection of received signals.

FIGURE D-9
Simplified Block Diagram of
Typical Airborne DME Transponder



Values of Typical System Parameters:

- Frequency range - 1025 to 1150 MHz
- Output power - 50 to 2000 watts (peak)
- Pulsewidth - 3 to 4 μs
- Pulse rate - 20 to 150 pulses/sec
- Rise/fall time - < 3 μs
- Carrier - stability ± 100 kHz

A simplified block diagram of a typical MTI radar is shown in Figure D-10. The received echo pulse (a frequency equal to the transmit frequency plus Doppler shift) is amplified in the RF preamplifier and down converted to IF. The IF amplifier stage output is fed to a coherent phase detector which yields bipolar video pulses, amplitude modulated at the Doppler shift frequency. In current radars, MTI is extracted from the phase-detector output by means of either delay-line canceller circuits or digital pulse cancellation. The trend is clearly to using shift-register storage elements to perform digital pulse cancellation.

Technological advances in surveillance radars fielded between 1985 and 2000 are not expected to create metrology problems, except, as previously stated, in the area of fiber optics equipment.

D.2.3 Microwave Landing Systems

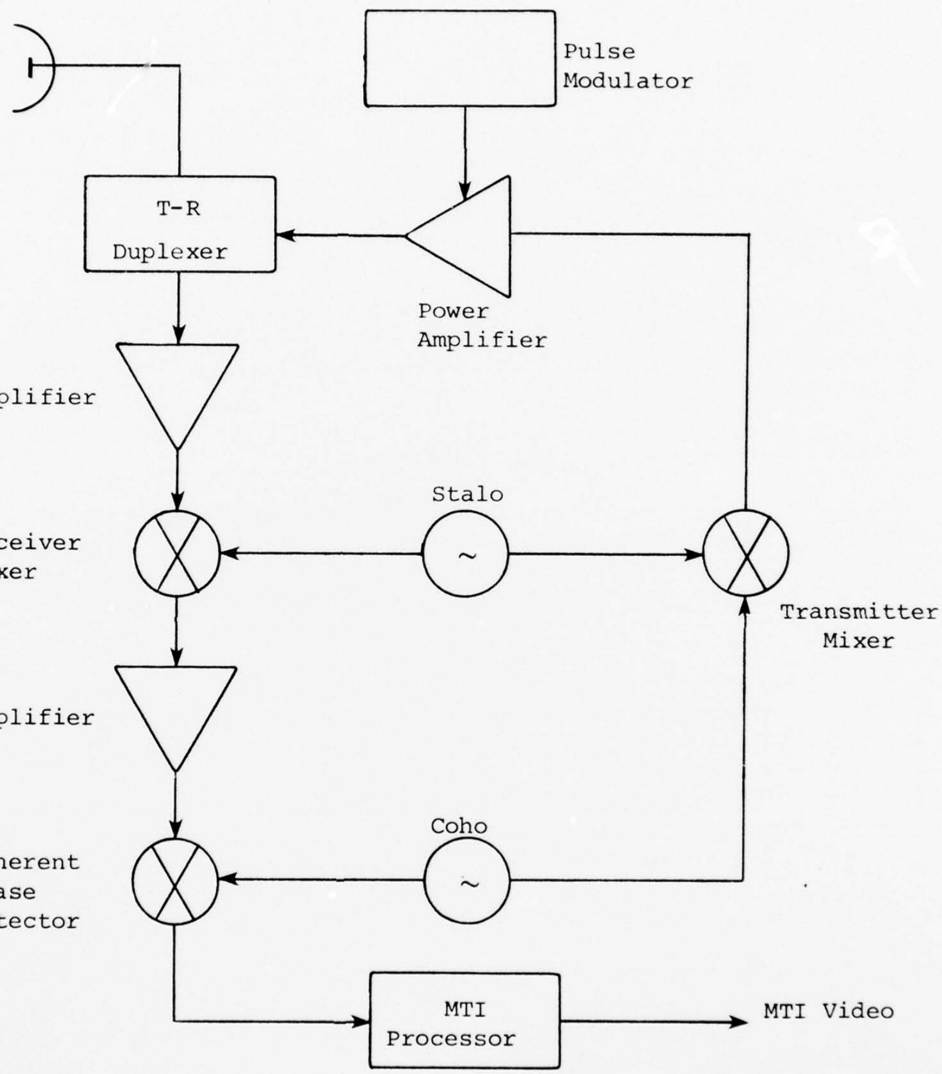
Microwave landing systems (MLS) were developed to overcome the limitations of VHF-UHF instrument landing systems and to provide several new features such as a curved landing/approach capability and a precision DME facility.

Figure D-11 depicts a block diagram of a typical airborne scanning beam MLS equipment. In this approach, azimuth and elevation angle information is obtained by an airborne receiver as it passes through a coverage volume in space. (This space is illuminated by rapidly scanned narrow fan beams generated by the ground equipment, which transmit narrow-deviation, angle-modulation, multitone-coded signals.) These signals contain information on antenna scan angle, runway identity, and other auxiliary data.

An alternative to the scanning beam system is the Doppler scan technique. In this approach, individual elements of a linear array are sequentially excited to simulate a moving source. This motion produces a signal in space with a Doppler-shifted frequency that depends on the angular direction of the receiver relative to the moving source. To measure such a small frequency shift, a nearby reference carrier is also transmitted from a fixed antenna.

Each approach has its advantages and further analysis is being performed on both techniques.

FIGURE D-10
Simplified Block Diagram of
Typical Surveillance Radar



Values of Typical System Parameters:

- Operating frequency - 1 to 3 GHz
- Output power - 5 MW (peak)
- Pulsewidth - 0.6 to 2 μs
- Pulse rate - 300 to 10,000 pulses/sec
- Carrier frequency stability - 0.005%

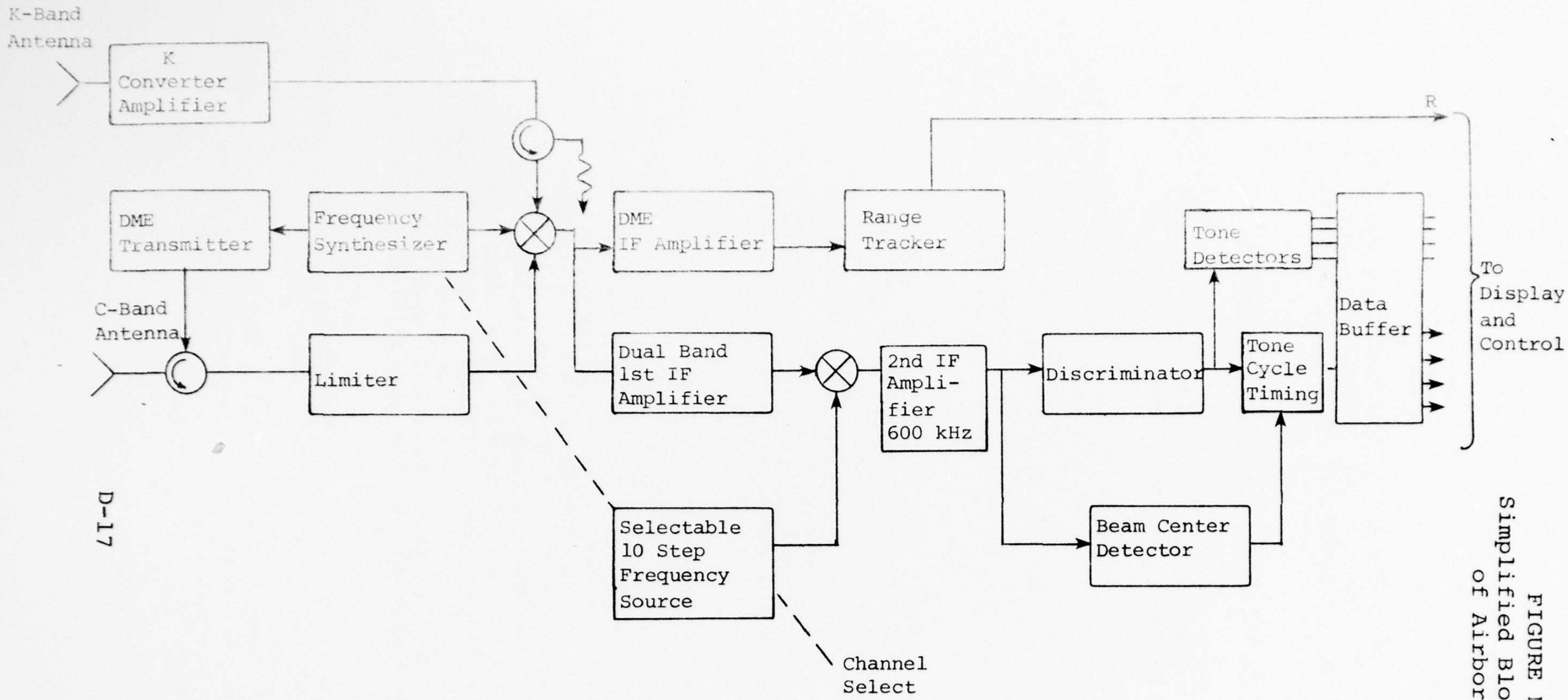


FIGURE D-11
Simplified Block Diagram
of Airborne MLS

Values of Typical System Parameters:

- Operating frequency - 50 to 35 GHz
- Output power - 50 kW (peak)
- Pulsewidth - 0.2 to 0.7 μs
- Pulse rate - 40 to 2000 pulses/sec

No matter which system is ultimately developed, technological advances are not expected to create any serious metrology problems for MLS deployed in the 1985-2000 time frame.

D.2.4 Collision Avoidance System Equipment

While a number of collision avoidance systems (CAS) are currently available, the time-frequency (T-F) airborne CAS is the one primarily used by the military.

The T-F concept depends upon precise synchronization of cooperative airborne transceivers. Highly stable reference oscillators, controlled by cesium-beam atomic clocks are required, either in the air or in ground stations, to synchronize the airborne systems of participating aircraft. The following describes a system, which is generally representative of T-F systems.

The time-frequency CAS is a coherent Doppler system in which each aircraft in a given volume of airspace is assigned a time slot, during which it broadcasts information regarding its position and altitude. Since each time slot is accurately assigned, and the transmission frequency precisely set, accurate range and range-rate data can be deduced from on-board processing equipment using the signals received from other aircraft.

During each message slot, two pulses are transmitted. The first has a total duration of 200 μs, and contains a preamble and postamble, each 40-μs long, for range determination. Receiving aircraft detect the time of arrival of this pulse versus the start of the assigned message slot, which is known to all participants who are properly time-synchronized. Range is then accurately computed from the measured signal-propagation time. Since transmission frequencies are coherent, range rate and sense are determined by measuring the Doppler frequency shift, referred to the known transmitted frequency. Accurate measurement of range and range rate are critically dependent upon proper time and frequency synchronism between transmitting and receiving aircraft.

The remaining 120 μs are available to transmit aircraft identification or other significant data.

The period between the end of the first pulse and the beginning of the second pulse is used as an analog of altitude of the transmitting aircraft, obtained from an on-board altimeter.

A simplified block diagram of a time-frequency CAS is shown in Figure D-12.

Recently, transponder-type CAS have been developed and tested. The operation of the system is similar to DME systems. The transponder CAS differs fundamentally from T-F in several respects, including:

- It is a non-synchronous system; that is, probe transmissions from different aircraft need not be coherent in time, nor is extremely high-frequency stability required. Ground stations are unnecessary.

- Range is measured on the basis of a received reply to an interrogating signal, with two-way propagation time the determinant, rather that by means of the one-way propagation-time measurement used in T-F.

- Range rate is computed from range measurements by integrating over a period of time and computing the rate of change of range from the results, as in radar tracking, rather than by the Doppler measurements of T-F.

The transponder type CAS is expected to find increased use in military CAS fielded between 1985 and 2000. It is also expected that technological advances in CAS will not cause any serious metrology problems for a CAS fielded between 1985 and 2000.

D.3 TARGET DETECTION AND ACQUISITION

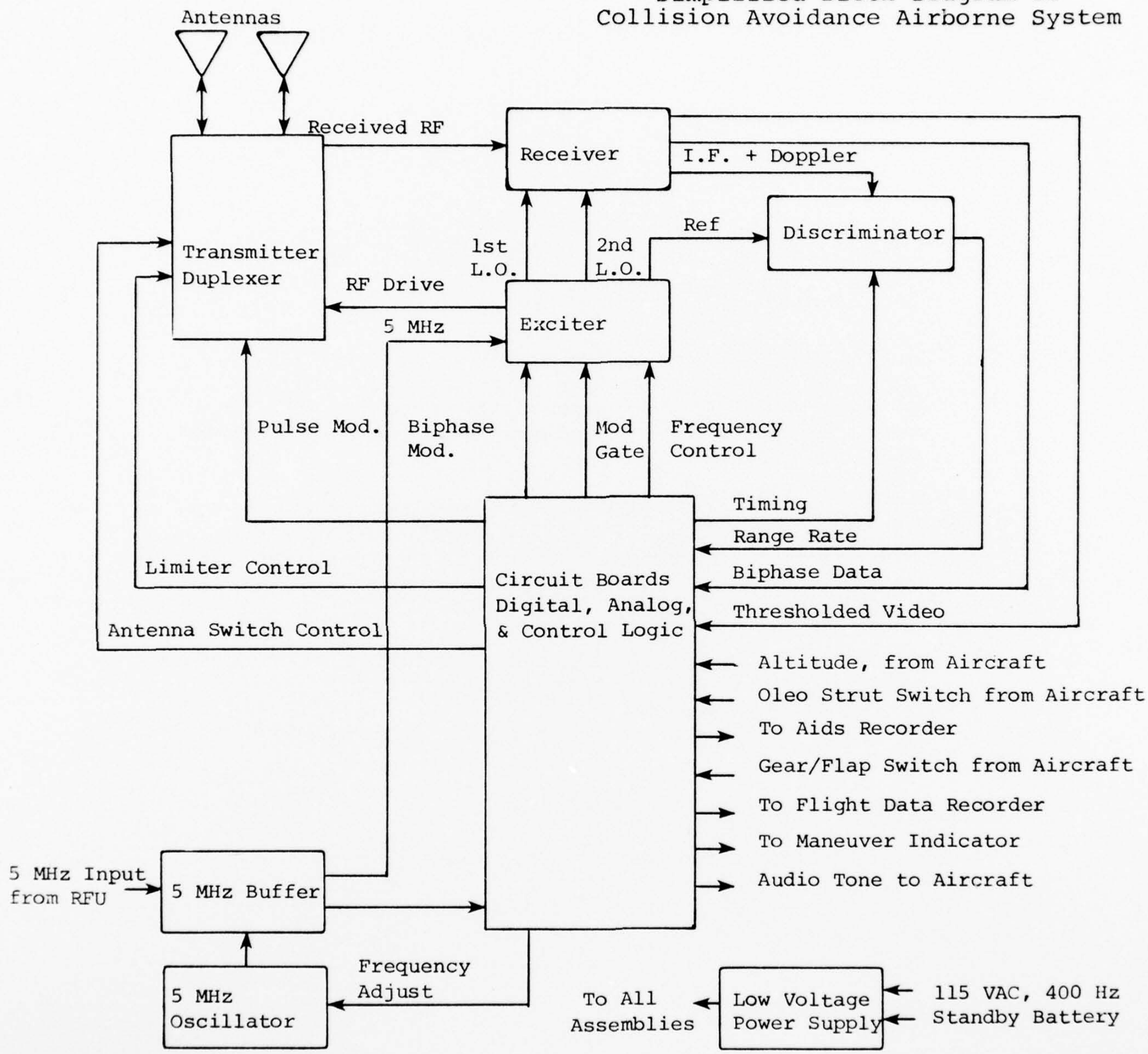
The development of equipment and systems to locate enemy weapons (artillery, mortars, and rockets) has a high priority within the Army. While several development programs are currently in progress, this discussion will focus on two which have potential metrology problems:

- FIREFINDER

- Remotely Monitored Battlefield Sensor System (REMBASS).

The reason for locating enemy weapons systems is to initiate countermeasures. Therefore, two fire control systems, which are basically the same and are presently completing development, will also be discussed in this subsection.

FIGURE D-12
Simplified Block Diagram of
Collision Avoidance Airborne System



Values of Typical System Parameters:

- Operating frequency - 1.6 to 5 GHz
- Output power - 100 to 200 watts (peak)
- Pulsewidth - 25 to 40 μs
- Pulse rate - 50 to 1000 pulses/sec

D.3.1 FIREFINDER

Presently, two distinct development programs exist within FIREFINDER: the Mortar Locating Radar, AN/TPQ-36, and the Artillery Locating Radar, AN/TPQ-37. The functional block diagrams for these units are very similar and are shown in Figure D-13. The main differences in the equipment parameters for these radar sets are the range and accuracy. Both of these radar sets are scheduled to go into full-scale production after 1980. It is expected that other types of sensors, namely seismic/acoustic sensors, will be coupled with radar detectors in future FIREFINDER-developed equipment.

Since these units are presently under development, new advances in technology should have little impact on the metrology requirements of the FIREFINDER equipment fielded between 1985 and 2000. However, a potential testing problem exists if seismic/acoustic sensors are coupled with the radar. Further effort will be required to determine test requirements for these sensors.

D.3.2 REMBASS

The purpose of REMBASS is to provide an early warning surveillance and target acquisition capability in a worldwide, all weather, day-night environment. A simplified block diagram of REMBASS is shown in Figure D-14. The system will consist of:

- Remote sensing elements
- Relay elements
- Monitoring/readout elements.

The remote sensing elements are expected to include:

- Seismic sensors
- Magnetic sensors
- Acoustic sensors
- Optical imagining sensors
- Chemical sensors.

It is expected that REMBASS will enter the engineering development phase with a relatively simple system consisting primarily of seismic sensors. Additional advanced development will continue in areas judged insufficiently mature for full-scale development. Full-scale production of the basic system is expected to begin in 1981; full-scale production of the sophisticated system is expected to begin by 1983.

FIGURE D-13
Block Diagram of FIREFINDER

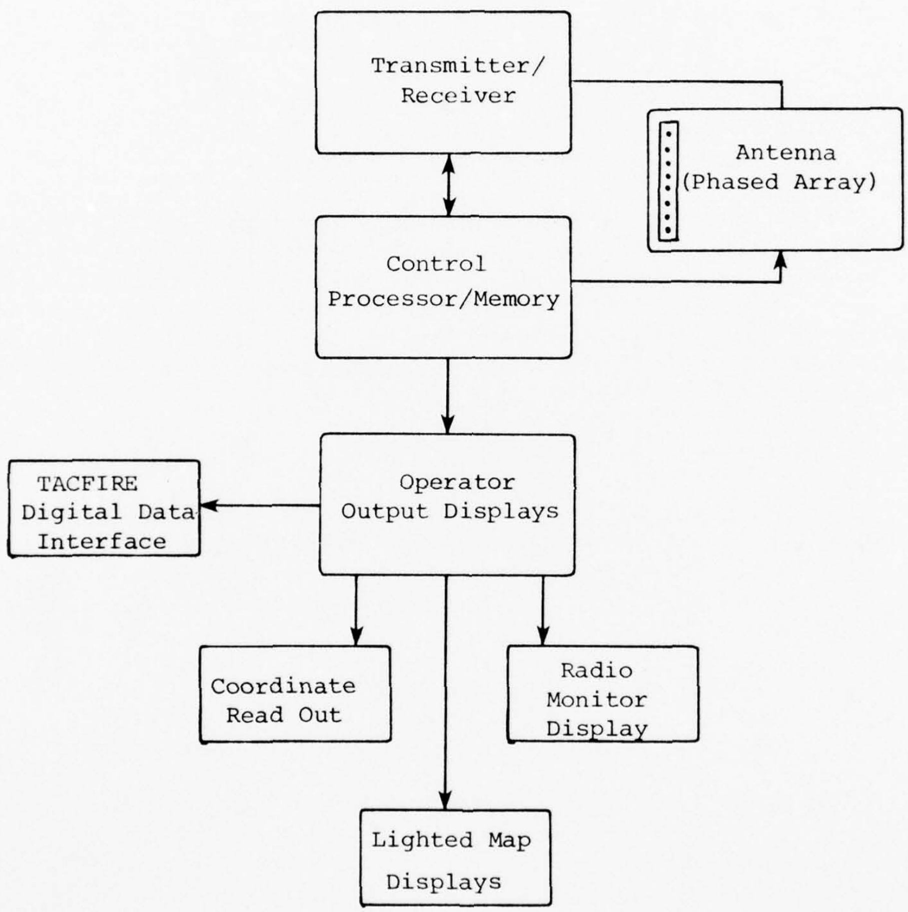
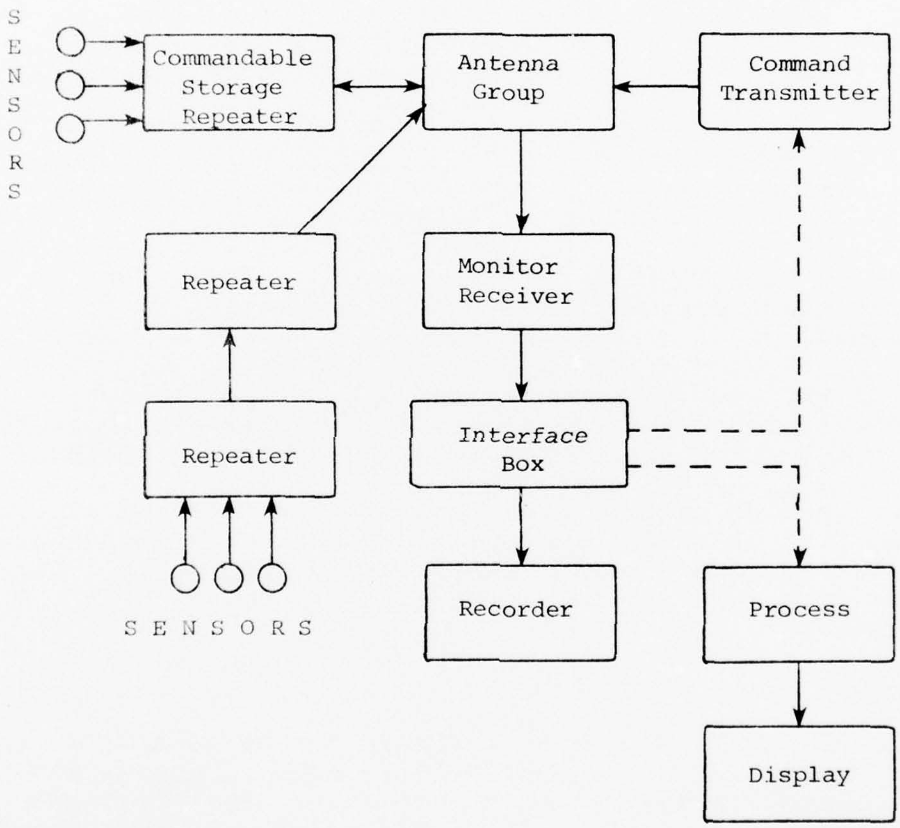


FIGURE D-14
Block Diagram of
Remotely Monitored Battlefield
Sensor System (REMBASS)



Since REMBASS is still in early development stages, it is expected that recent and advanced technolgoy will be used in this equipment. Therefore, it is likely that the LSI technology used in this equipment will tend to be CMOS and I^2L as a result of the requirements for real-time processing and low power consumption.

D.3.3 TACFIRE

TACFIRE is an automated artillery fire control system. To compute the location of enemy artillery batteries, the TACFIRE computer uses inputs from several sensor sources, including:

- REMBASS
- FIREFINDER
- Forward artillery observers.

In addition, the TACFIRE computer inputs information and available resources determine the optimum means to take countermeasures.

Once the TACFIRE computer has determined the action to be taken, it formulates a message to the artillery battery computer detailing the coordinates and charge to be fixed.

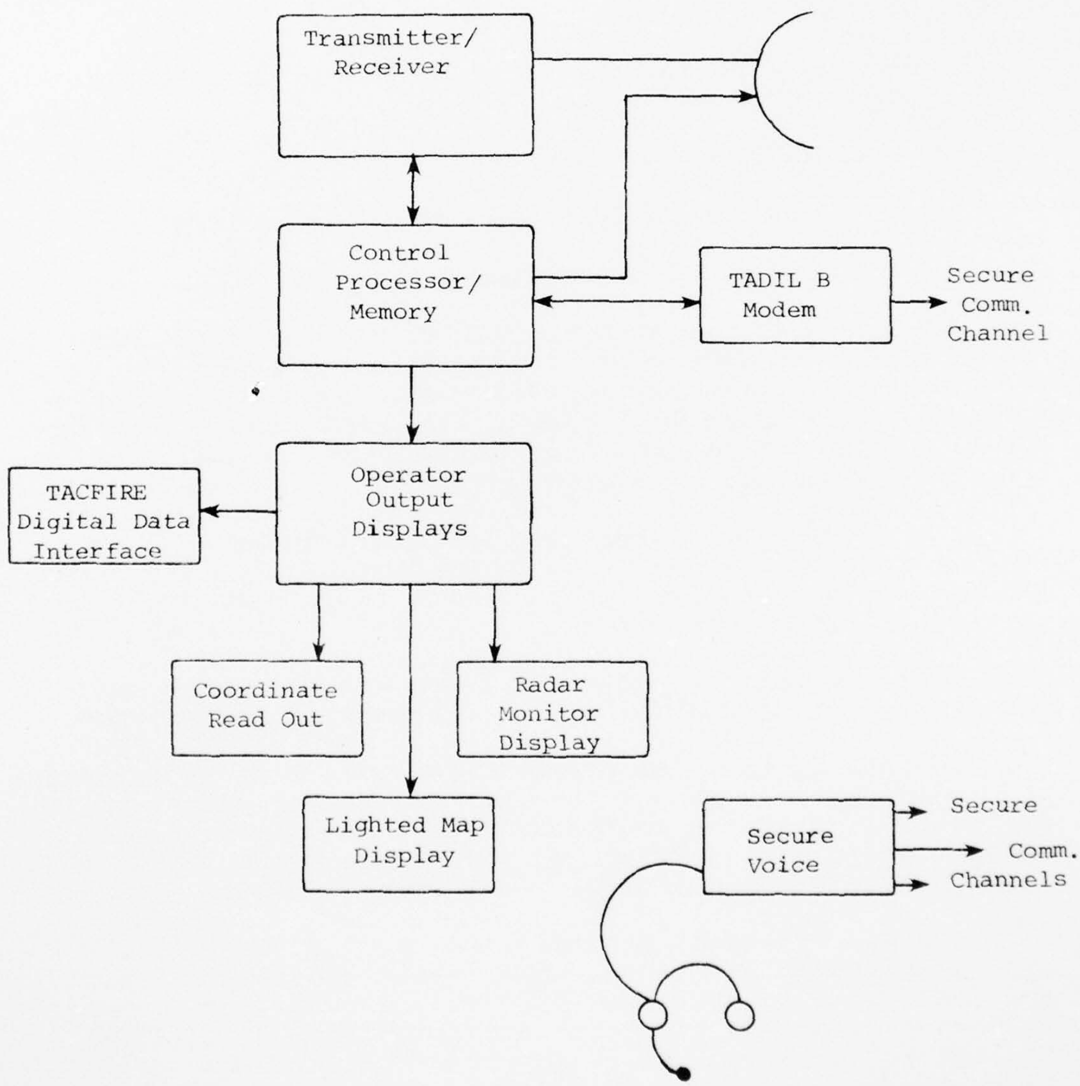
The TACFIRE system is currently being fielded; it is expected that this equipment will be in the field throughout the 1985-2000 time period. Since the technology is typical of 1970s computer systems, no metrology problems are anticipated.

D.3.4 Missileminder System

The AN/TSQ-73 HAWK missileminder system is similar in concept to TACFIRE. The AN/TSQ-73 is used to manage HAWK missile batteries against enemy aircraft. The principal sensor input to the AN/TSQ-73 is MTI radar. In addition, the AN/TSQ-73 must compute three-, rather than two-, dimensional target coordinates. Figure D-15 shows a simplified block diagram of the AN/TSQ-73.

The technology used in the AN/TSQ-73 is typical of 1970s processor-equipped systems. Since it is expected that this system will still be in the field during the 1985-2000 time period, no metrology problems are anticipated for this equipment item.

FIGURE D-15
Block Diagram of
AN/TSQ-73 TACS/TADS



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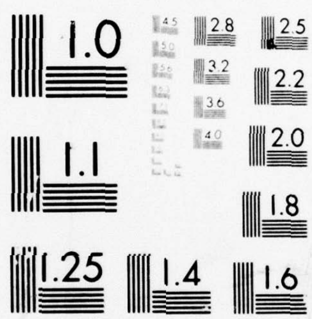


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

D.4 ELECTRONIC WARFARE EQUIPMENT

EW is the military use of electronics to:

- Prevent or reduce an enemy's effective use of radiated electromagnetic energy

- Insure our own effective use of radiated electromagnetic energy.

Following from this definition, EW can be subdivided into three major areas:

- Electronic countermeasures (ECM)

- Electronic warfare support measures (ESM)

- Electronic counter-countermeasures (ECCM).

ECM are actions taken to prevent or reduce the effectiveness of enemy equipment and tactics employing or affected by electromagnetic radiation, and to exploit the enemy's use of these radiations. The most common form of ECM is active jamming which is used for both communications and non-communications systems.

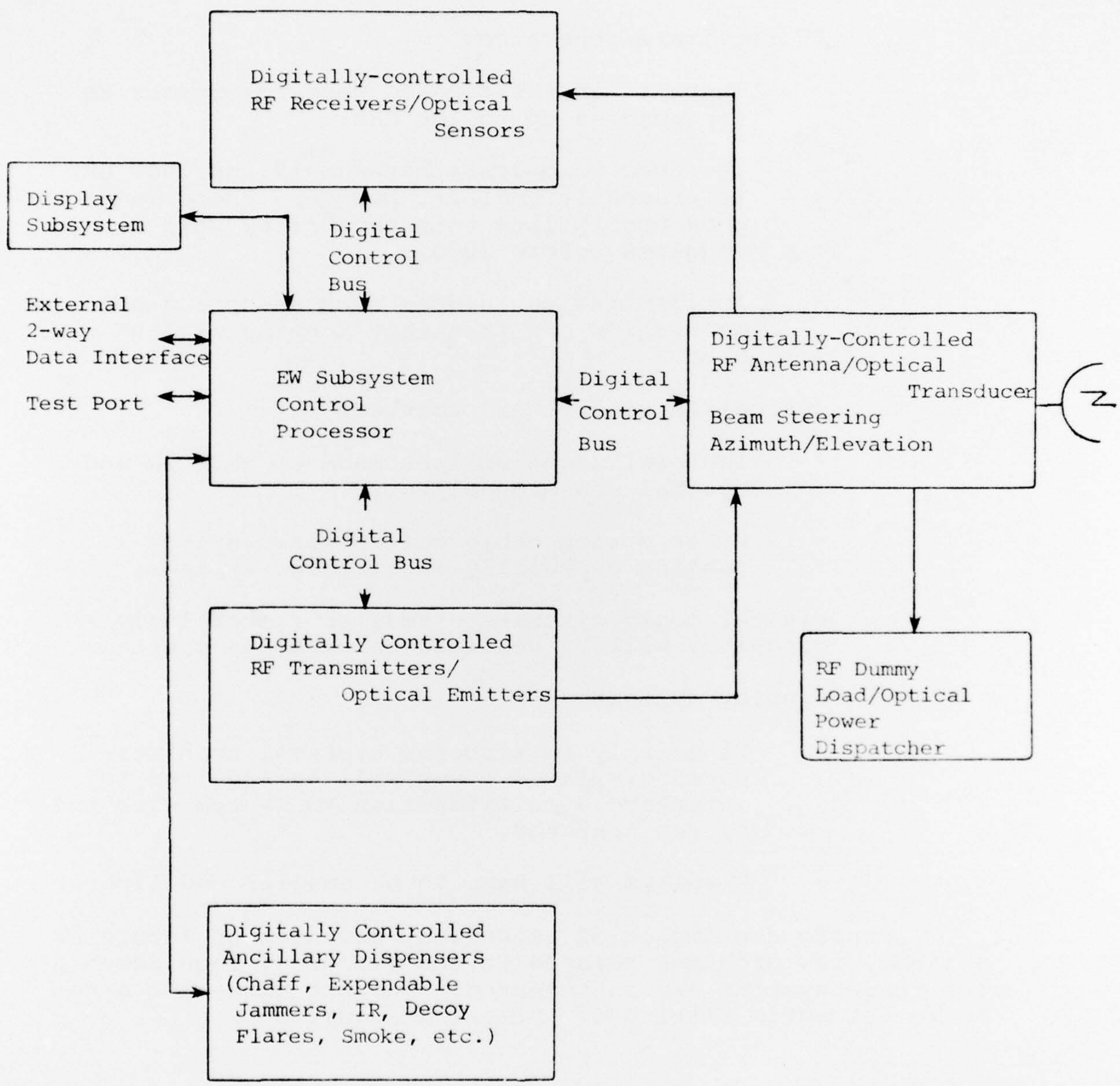
ESM are actions taken to search for, intercept, locate, record, and analyze radiation in support of military operations. As such, ESM provides a source of information required to conduct other forms of EW.

ECCM are actions taken to insure the effective use of electromagnetic radiation in the presence of a enemy ECM.

Because of the highly classified nature of EW equipment and techniques, it is not possible to present detailed system configurations and parameters. Rather, a general configuration will be used to discuss equipment trends which will impact future metrology requirements.

Figure D-16 shows a simplified block diagram of a typical airborne EW system. The system contains RF receivers and optical/IR sensors used primarily for ESM and RF transmitters and optical emitters used for both ECM and ECCM. The control processor is a significant item in the sophisticated EW system. The complexity of present EW systems mandates that a processor be used to control ESM and ECM/ECCM activities. In the 1985 to 2000 time frame, the control processor will be required to perform even more complex functions to match the enemy threat level.

FIGURE D-16
Simplified Block Diagram of
Typical Airborne EW System



Future EW systems are dependent on several technologies, including:

- RF receivers/generators
  - There is an anticipated need to operate at frequencies up to 100 GHz.
  - The need to operate between 10 and 1000 GHz is presently unclear, however, there is a good possibility this capability will be required before 2000.
  - Antijamming techniques such as spread-spectrum modulation and frequency hopping will be used.
- Optical/IR sensors and emitters
  - Increasing use will be made of both IR and optical sensors/emitters.
  - Fiber optics cable will replace system cabling especially in airborne systems.
- Digital logic circuits - smaller faster logic circuitry will be required in airborne systems.
- Display systems
  - Especially in airborne systems, sophisticated display systems will be required to interface a multifunction EW system with the system operator.
  - Displays will have to be smaller and lighter.

Despite the impact of technology advances on future EW systems, few problems related to the metrology requirements for these systems are anticipated. The one high-risk area is in automatic testing of optical/IR equipment.